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HUMAN FACTORS

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PREFACE

Many of the man-made products and environments of our civilization are created by people, for use by people in their everyday lives as in our mission, the defense of our nation. In many such instances the design features of the products and environments directly influence the success of the mission; this often results in the ultimate bottom line, mission success or failure, life or death. This text deals with some of the problems and processes that are involved in man's efforts to design an aircraft and pilot/aircrew interface so they optimally serve their intended use. In today's environment of high technology, we design aircraft with exceptional performance, agility, and complexity, such that the operator(s), the human, has become the weak link, the limiting factor of the weapons system. This effort constitutes an attempt to expose you as evaluators of weapons systems to some of the areas of concern where man and machine meet.

This text represents a combined effort of the USAF Test Pilot School, Edwards AFB, CA, and the USAF Academy, Colorado Springs, CO, for use in the Test Pilot School curriculum. This effort is intended as a survey of human factors engineering relating to primarily cockpit design and its environment. In line with this objective, the text deals with several of the most important aspects of human factors. In the case of each such topic it has been the intent to delineate it, to characterize its major dimensions and related concepts, and to present some of the research that is relevant to it. Although practical requirements have made it necessary to be selective in the inclusion of material for this publication, numerous references are provided for the reader to pursue an indepth study of the subject material.

The text is arranged such that each chapter begins with lists of the lesson objectives and suggested additional reading. This will give the reader a brief idea of the chapter goals along with certain additional reading which will substantiate or supplement the material in each chapter. Appendix A constitutes the United States Navy Test Pilot School Human Factors Handout. Although no author or publication date is given, this handout contains some good reading material which would be otherwise difficult to obtain. For your further reference, a list of other reference materials and specifications are contained in Appendix B.

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CHAPTER ONE - CONTROLS

LESSON OBJECTIVES

1. Describe the impact of control design on system performance.
2. Describe major control types.
3. Identify types of control design-induced errors.
4. Understand control parameters which affect design-induced error.
5. Recommend changes in control parameters to reduce error.

SUGGESTED ADDITIONAL READING

McCormick, R. J. and Sanders, M. S., Human Factors in Engineering and Design, Chapter 9.

Van Cott, H. P. and Kinkade, R. G., Human Engineering Guide to Equipment Design, Chapter 8.

Woodson, W. E., Human Factors Design Handbook, Chapter 3.

CONTROLS

Control design is one of the central areas of concern in Human Factors Engineering. In fact, it was a control design problem which was involved in the recognition of human factors as an important aspect of systems design. Basically, a rash of P-47 accidents were attributed to confusion of two controls, flaps and landing hear, by pilots who had been trained on an aircraft in which the position of these controls were reversed from their position in the P-47. Rather than simply blaming aircraft accidents on mistakes made by pilots, it became evident that the identification of design-induced errors could lead to improved safety and performance. A more current example of design induced error involves the isometric stick of the F-16. In its initial design the stick was truly isometric--it did not move at all. With a conventional stick, you get feedback regarding the position of the stick from sensors in y our joints and muscles. This feedback is called proprioception. It is this sense which allows you to touch your nose with your eyes closed. However, this feedback is absent with a non-moving control. Therefore, the only feedback you would get would be from pressure receptors in the hand. However, the feedback from these receptors is not very accurate or reliable, especially when wearing gloves. For these reasons, the F-16 with the isometric stick was extremely difficult to fly. Current versions of the F-16 stick move a small amount (± 1/8"), providing enough proprioceptive feedback to make the aircraft controllable.

Before describing control design parameters in detail, a brief description of major control types may be helpful.

CONTROL TYPES

DISCRETE CONTROLS

1. Toggle Switches. These may be the traditional two-position switches, or may have a center plus two extreme positions (three-way), or may move in four directions. They can either stay in the position selected, providing visual feedback, or may be momentary-contact.

2. Push Button. Primarily used for switching between two system states (e.g., ON-OFF), but may also be used to step through a sequence of actions or displays. Operation is usually momentary contact, or push-on, push-off.

3. Circuit Breakers. A specialized form of push button, with push-on, pull-off operation.

4. Rotary. Usually involving a know that can be set to four or more positions.

CONTINUOUS CONTROLS

1. Tracking. A control which is constantly adjusted to track some desired system output or parameter. The best cockpit example is the stick.

2. Adjustable. Can be set to any desired position, such as the throttle or a volume control.

COMBINATION AND TIME-SHARED CONTROLS

1. Integrated. One control which can operate in several modes (e.g., a 4-way switch which can also be pushed in: toggle + push button).

2. Stacked. One or more controls mounted on another (e.g., the controls mounted on the stick and throttle).

3. Multifunction. Controls which do different things at different times (e.g., the buttons on a multifunction display).

DESIGN-INDUCED ERROR

As test pilots, you are concerned with whether or not the control configuration allows you to perform all necessary operations. This means that you are able to operate the controls in such a way that the system responds in the manner desired, to the required level of accuracy, within the allotted time, and with an acceptable error rate. Given that emphasis, it is useful to evaluate control design in terms of the kinds of mistakes one makes when operating the control. In the largest sense, an error can be defined as any inadequate control input, whether in time, speed, direction, or magnitude of activation. The following is a list of design-induced control input errors, along with descriptions of the design parameters which might cause the errors.

REACH

The control is difficult or impossible to reach. This problem is generally caused by the physical location of the control. Put simply, your arm, leg, or fingers (or any body part used to operate a control) may not be long enough to reach the control. Also, reaching the control may take more joint bending than is possible. However, being able to reach a control may not be sufficient; you must be able to reach it under all operational conditions that require its operation. For example, there might be a switch which requires you to lean forward to operate it. If that switch must be operated under high-G conditions, it may be outside your functional reach at that time.

Controls which are outside your visual field may also be difficult to reach. If your inability to see a control under some or all operational conditions restricts your ability to find it. It may be appropriate to consider relocation.

One must keep in mind, however, that the prime real estate in the cockpit is limited, and some controls must be placed in sub-optimal locations. Therefore, it is often necessary to trade off location with frequency of use and criticality.

INADVERTENT OPERATION

Location can also play a big part in inadvertent activation. For example, if one control is in close proximity to some other control, you might accidentally bump one while operating the other. Or, if a control is in the natural resting point of some body part (e.g., under the fingers on the stick), it might be activated during turbulence or high-G maneuvers.

As stated before, it may be impossible to put each control in its "optimum" location. Or, for highly time--critical controls, it may be necessary to place them where they can be quickly and easily operated. For these controls, inadvertent operation could be reduced or eliminated by guarding (covers, shields, etc.) or by increasing the amount of force necessary for operation.

CONTROL CONFUSION

There have been many instances of control design which caused confusion, making it easy to grab the wrong one. The example in the introduction was one such case. Another exists in nuclear power plants, where forty or more identical switches may be lined up in a row with equal spacing. The only way to distinguish among them is

by reading the placard under each one. If two or more controls look or feel nearly alike, it may be easy to confuse them, especially when under high stress or during rapid operation.

To reduce these problems, controls can be coded in a number of ways. For those controls which you can look at prior to operation (assuming adequate lighting), color can provide some help. For example emergency controls can be given yellow and black stripes. Varying shape and size can also be helpful and have the added advantage of being useful when you can't look at the control (provided you can distinguish the size and shape by feel). For those controls which must be located without looking at them, placing them far enough apart can also aid discrimination (location coding).

One other type of control coding is by method of operation. If two controls are frequently confused, they could be designed so that the way in which they are activated differs. For example, if there are two toggle switches, one could be redesigned as a push button.

Another source of confusion among controls is called negative transfer. This phenomenon occurs when a control is in a location which differs from your past experience. The example P-47 in the introduction illustrates this problem. When a control in the aircraft you're testing is in some location which is different from your past experience in other aircraft, and this difference causes you to make errors, negative transfer has occurred.

As aircraft become more highly automated, a new kind of problem develops. Multifunction controls may do different things at different times. In these cases, operating the control at the wrong time is equivalent to operating the wrong control.

DIRECTION OF OPERATION

Most of us develop an expectation for the way a control should operate. When a group of people all expect a control to operate in the same way, we say there is a "population stereotype". An example is our expectation that a light switch should be flipped "up" to turn the lights on. If you entered a room in which the switches worked in the opposite direction, you would probably make errors. The control operation would be opposite to you (and most Americans') stereotype. The point to understand is that if the control operation is contrary to your "natural" expectations, errors can result.

ADJUSTMENT

One of the designs criteria which can affect ease of adjustment is sensitivity or gain. Sensitivity is the amount of change in the system or display (D) compared to the amount of control input (C). With a sensitive control, a small input will cause a large change in output. Human factors engineers usually prefer to use the inverse of sensitivity, which is called the control-display ratio (C/D). A highly sensitive (high gain) control has a low C/D ratio. If a control is too sensitive (low C/D), it may be difficult to adjust it smoothly or accurately. On the other hand, if C/D is too high, it may take too long or too much control input to get the system to respond.

A number of other design factors can influence control adjustment. If the control is too big or too small, or if it must be operated "blind", adjustments can be difficult. Excessive damping can require too much force to operate the control.

ACCURACY

If the physical range of control adjustment is too compressed, the individual settings may be too close together to be discriminable. Conversely, if there are an excessive number of possible settings, the same problem can occur.

CONCLUSION

You must remember that the kinds of errors described above are not "caused" by the pilot. Tkhey are design deficiencies which trap the pilot, making their occurence much more likely. Many or all of them can be minimized by proper design which takes into account the inherent capabilities and limitations of human operators.

CHAPTER TWO

VISUAL AND AUDITORY DISPLAYS

LESSON OBJECTIVES

1. Be familiar with visual display guidelines related to content, precision, format, redundancy, failure indications, location and arrangement, and coding.

2. Understand the differences between pursuit and compensatory displays.

3. Be familiar with the important considerations for the evaluation of auditory displays.

4. Be familiar with the recommendations as to the use of visual versus auditory displays.

SUGGESTED ADDITIONAL READING

Bailey, R. W., Human Performance Engineering: A Guide for System Designers, Chapter 4.

Huchingson, R. D., New Horizons for Human Factors in Design, Chapter 4.

Human Engineering Design Criteria for Military Systems, Equipment, and Facilities, MIL-STD-1472C, Chapter 5.

Human Engineering Guide to Equipment Design, Van Cott, H. P. and Kinkade, R. G., Chapter 4.

Human Factors Engineering, USAF AFSC Design Handbook, DH 1-3, Section 2B.

McCormick, R. J. and Sanders, M. S., Human Factors in Engineering and Design, Chapters 4 and 5.

Woodson, W. E., Human Factors Design Handbook, Chapter 3.

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VISUAL AND AUDITORY DISPLAYS

The two most common means of communication are through or sensory modalities of vision and audition. It is important to understand how that communication is accomplished via displays. Knowledge of general guidelines, types of displays, location and arrangement, coding, and other considerations will aid in evaluating airborne cockpit systems. The purpose of this section is to present information to be used in evaluating visual and auditory displays.

VISUAL DISPLAY CONSIDERATIONS

Visual displays are the most common means of presenting information in an aircraft. These displays aid our sensory inputs because of the limited amount of information that humans can process. For example, how often have you tried to estimate speed. Without a speedometer it's very difficult to be accurate. The same goes for measuring a line correctly without a ruler. Consequently, in order to properly design visual displays, adequate attention must be given to guidelines concerning content, precision, format, redundancy, failure indications, location and arrangement, and coding.

CONTENT

When content value of a visual display is discussed, it deals with the simplest display. Give the operator only what he/she needs to make a decision. The more complex, the more time it takes to read and decipher what is meant. If the display is used to convey a simple message the odds are that the message will be received and understood.

PRECISION

The less precision required by an operator to interpret a given message, the faster will be the response to the display. Generally, faster operator responses produce less fatigue, mental stress, and unnecessary errors.

FORMAT

Using the most expected or natural display format will decrease response time. Unfamiliar formats increase errors in reading and deciphering. Additionally, unfamiliar formats interfere with established habit patterns. Maintaining habit patterns such as an increase in value means to the right, up, or clockwise supports stereotypic expectations and compatibility.

REDUNDANCY

Redundancy in visual displays can be described as using an additional coding method with a primary display method. An example of this is a stop light with the appropriate colors plus the words STOP and GO.

FAILURE

If the display fails, an indicator alerting the operator should be included. This does not mean an auxiliary display but rather the malfunction should be fairly obvious, e.g., a warning flag appears on the instrument.

LOCATION AND ARRANGEMENT

1. Viewing Considerations. Even the best equipped crew station can be the weak link in the man-machine system, particularly when those "best conceived" displays cannot be seen or interpreted. Proper installation and appropriate illumination enhance the utility of the visual display.

2. Viewing Distance. Most references, e.g., MIL-STD-1472C, AFSC DH 1-3 and others, specify an optimum viewing distance of between 510 mm (20 in) and 653 mm (25 in) for conventional instrument displays. Optimum for CRT's is between 254 mm (10 in) and 406 mm (16 in). However, these distances are not hard and fast rules, and therefore should be modified to fit the task. For example, crew stations such as those for the flight engineer, navigator and radar operator generally employ a 711 mm (28 in) viewing distance. This distance is generally within a comfortable "arms reach". A little further out, 260 mm (30 in), is the distance specified by MIL-STD-1472C for all ejection seat crew stations. Some forward instrument panels in the larger transport aircraft approach 915 mm (36 in). Regardless of the distance, the display, to be useable, must be readable. A case in point is the oil pressure gauge on the F-16. The viewing distance is approximately 30 inches and the instrument is fairly small and difficult to read. As a result, pilots report that in most instances when oil pressure problems occur, the pilot does not recognize it until the oil pressure warning light comes on. Therefore, when distances exceed the optimum, design considerations (size of characters, scales, etc.) become all that more crucial. Obviously, the bottom line is this: Can the display be interpreted correctly, consistently, and with minimal error?

3. Visual Angle. Refer to MIL-STD-1472C, Figure 1. Visual angle refers to the angle formed by the normal line of sight (LOS), and the display instrument face. To

better understand LOS, assume that a pilot (with average seating height) is looking through the HUD of an F-106. If he were to look down at an angle of approximately 15°, he would be looking in the neighborhood of the main ADI. This 15° below horizontal is the LOS. Ideally, the instrument (display) face should be perpendicular to LOS, thus the pilot can view the display "straight on". Some displays in the F-16 are tilted and thus approximate the ideal. Many cockpits, however, don't even come close. For example, in some transport aircraft, the crewmembers must strain to even see, much less read, some displays. To prevent the resulting distortion and parallax when these angles become extreme, design considerations for legibility once again become critical.

4. Illumination. Considerations for instrument lighting are essentially the same as those for the general crew station environment (see Workplace Design in this text, General Illumination Requirements - Navy TPS Handout, and AFSC DH 1-3). Regardless of type (background, rear, wedge, electroluminescent, flood, etc.), two principles apply. First, the amount and type of illumination is task specific (McCormick and Sanders, 1982). Depending upon the task at hand, the operator must have appropriate lighting during periods of darkness. Second, the operator should have appropriate controls to adjust the amount of light (this does not include masking tape), within a variable range of full-up to off. For example, full-up on the A-10 IFF panel is still far too dim. Also included in this control capability is the need for all displays on the respective panel to be at the same level of illumination, i.e., when the rheostat is adjusted, <u>all</u> of the affected displays should vary at the same intensity. The F-106 is a good example of the ideal. Discounting the problem of canopy reflections, the F-15 and F-16 also have good instrument lighting control capability. The T-33 and C-130B, however, are at the opposite end of the spectrum.

5. Functional Arrangement. Related to the mechanics of viewing distance and angle, are location and grouping. These terms answer the questions, "which displays go where?" and "How can we put the puzzle together so that it makes sense?"

6. Location. Location means exactly that, but more importantly, where can the displays be placed so that the operator can obtain precisely the information he needs, when he wants it, with minimal effort. Obviously, the primary or most frequently used displays should be placed conspicuously "up front". Ideally, they should all be placed within a 30° cone which has a normal LOS as its center. See MIL-STD-1427C, Figure 2, for a description of the visual field. Unfortunately, this area is small. Therefore, a general rule is that instruments should spread out, away from LOS,

according to decreasing frequency of use. Reasonably good examples of this concept are the F-5, F-15, and F-4. Surprisingly, an older aircraft, the F-106, has most of the primary displays within the 30° cone.

The position of a display can also have an undesirable side effect, that of excessive reflection and glare. Although this problem can be aided by relocating the instrument, the use of light filters, glazing or tilting the instrument face are more practical solutions.

7. Grouping. This is an old and obvious concept. Essentially it means that displays with related functions should be positioned close together. Logically, all of the engine instruments are together. Also, the primary flight instruments should geographically form their own group. Presently, most aircraft conform to this principle.

CODING

A visual code is a method of transferring information, of communicating. Common examples of visual codes include the symbols on highway signs and markers, stop-lights, symbols for male and female restroom entrances, and so on. In fact, while reading this you are using a fairly sophisticated coding system that transmits written symbols into linguistic meaning. In the crew station there are many instances where visual coding is used. But unless you are really concerned with coding you probably have not noticed what is currently in the cockpit, nor the subtle changes which have occurred over the years. Most coding is taken for granted by aircrews, and since it has not changed significantly, only an introduction and familiarization of color, shape, location, line and inclination, and multiple coding will be provided here. New and future methods are left to the creativity of the reader. For a comprehensive discussion of visual display coding, see Van Cott & Kinkade, 1972.

1. Color Coding. Color is an old, but yet effective, method of coding which is a common tool of our everyday lives. Stoplights are color coded. Electric wires are color coded. However, in military crew stations color is now infrequently used on instrument displays. Civil aviation still uses the red, yellow, and green arcs on instruments such as airspeed, RPM, and oil pressure. But a requirement to fly at night has all but eliminated color on our instruments. The reason is that the red cockpit lighting (necessary for night vision) washes out other colors and thus makes surface colors indiscriminable.

However, color lights are another story. Here we use color coding for warning and caution as well as many status lights. MIL-STD-411 sets the requirements for colors

and the code to be conveyed. In crew stations, the most frequently used are red, yellow, and green. Red denotes emergency or unsafe. The flashing red light is the one which generally causes the pilot's heart to skip a beat. Yellow infers caution, such as the master caution light. Green indicates normal or function activated, such as gear down or locked. Other colored lights, such as blue, are used infrequently.

2. Shape Coding. This method makes use of symbols, geometric or pictorial shapes, and alphanumerics. Many automobile manufacturers have incorporated shape symbology in their cars. For example, the gas pump symbol is an alternative for the words fuel, gasoline, and petro. These symbols are now being used universally, and as a result have reduced production costs since the displays no longer require multi-language export models. Aircraft, however, have employed alphanumerics (letters and numbers) entirely, and probably will for some time. Pilots have been reluctant to cast aside the certainty of alphanumerics.

3. Location Coding. This method is quite simple but important nonetheless. Essentially, it promotes the idea that since the human operator has habits and becomes accustomed to seeing things in "proper places", designers should cater to these habits and keep those things in their "proper place". For example, engine instruments in single-seat aircraft are always in the mid to lower right side of the forward instrument panel (center for multi-place, larger aircraft). Most pilots <u>expect</u> to find engine displays located there. Even though sound evidence may support another area, placing these instruments may not receive user acceptance. In addition, follow-on models should be as consistent as possible with earlier models, particularly with respect to location coding.

4. Line Length and Inclination Coding. This code uses length and straight-line direction to transfer information. A multi-engine cockpit is a good example, and specifically engine instruments (again!). Those instruments with the same function (e.g., oil pressure for the respective engine) should be placed side by side so that when comparing, an out-of-tolerance reading should stand out as being "different." If the instruments are round dials, ideally all "normal" readings should be aligned to point in a cardinal direction, either horizontally or vertically. In the case of vertical instruments, a deviation can be read as either higher or lower than the horizontal reference line.

5. Multiple Coding. This method utilizes two or more meanings or codes within the same mechanism. For example, when an engine fire light illuminates, most systems come on red and flashing. This means danger, emergency, and a hot spot has been

detected. If the light then becomes steady (ceases flashing), then there is now a fire where there shouldn't be. In cases of multiple codes, designers must insure that the information or status that they depict is easily understood or quickly learned and that the codes themselves are congruent with the notion of habits presented earlier.

TYPES OF VISUAL DISPLAYS

DYNAMIC AND STATIC DISPLAYS

Further amplification of visual displays follows with a discussion of dynamic and static displays. Dynamic displays can be either quantitative or qualitative. Under the label of quantitative, there are three basic types: (1) fixed scales with moving pointers such as the RPM gauge; (2) moving scales fixed pointers; and (3) digital displays or counters such as calculator displays. Types one and two are analog displays while the third is related to electrical inputs rather than physical quantities.

When comparison is made among these types, some generalizations stand out. For example, if a signal can persist and the operator has time to respond, a digital display is far superior to either 1 or 2. If time is essential then it has been found that fixed scale-moving pointer displays are superior to moving scale-fixed pointers.

Qualitative displays are used when the primary interest is approximate values, trend, or rate of change of a continuously changing variable. Essentially a qualitative scale is used as a check-reading scale; that is, the value represented reflects what is normal (neutral, safe, satisfactory, etc.). An obvious example is an RPM gauge's red line value or the associated green area for safe operation.

Static displays, contrastingly, are stationary over time and are not connected to system outputs. These include alphanumeric tables, graphs, labels and so on. These are found in all areas of the aircraft, e.g., equipment name plates and operating instructions.

PICTORIAL AND SYMBOLIC DISPLAYS

Pictorial and symbolic displays include photographs of terrain, TV pictures, etc. In aircraft, these pictorial displays may be represented as contact analog or in a head-up-display (HUD). Symbolic displays can be seen in conventional engine instruments. For example, the tick marks indicate discrete parameter values. The fuel gauge is a symbolic instrument that is analogous to the physical magnitude it represents.

COMBINED/INTEGRATED DISPLAYS

These displays should be used only when the information is related. When used, an obvious advantage is saved panel space, reduction of eye scanning, and possible simplification of interpretation. Integrated displays, according to Huchingson (Chapter 4), treat the entire panel as a display. The real world is seen through the HUD while altitude, airspeed, pipper, etc., are projected onto it.

PURSUIT AND COMPENSATORY DISPLAYS

The pursuit display shows the movement of the target and the aircraft itself against common reference points. In this situation, the target movement represents the system input function. The aircraft movement indicates the system output. Finally, system error is represented as the distance between the aircraft and the target. An important characteristic of pursuit displays is the availability of both system input and output information to the operator.

In a compensatory display an operator sees only one moving element or "blip" and a fixed reference point. That blip represents two things simultaneously: where the controlled system currently is and what effect the most recent control input has on the system's position. Thus, unlike pursuit displays, the operator or pilot never sees a direct or unconfounded result of a control input. The distance between the blip and the reference point represents position error and it is the operator's task to null or eliminate the error. When the blip is centered on the reference point, proper control has been achieved.

Which is best? Well, for tracking a blip on a scope with you as the pursuer, the pursuit display is best. But an example of a compensatory display used well is the glideslop indicator. The pilot guides the plane for a landing by nulling error.

Regardless of display used, the pilot must have an idea of his/her present performance and dan idea of desired performance. Present performance reflects the position of aircraft as a result of the pilot's control actions, while the desired performance reflects where the aircraft should be. In most cases a pursuit display will best achieve this if true motion is desired.

SIGNAL AND WARNING DISPLAYS

These displays must be detectable. Detectability means certain criteria must be met for our human sensory and perceptual processes to actually respond.

Recommendations (McCormick & Sanders, Chapter 4) for signal and warning displays follow:

1. Use when actual or potentially dangerous condition may exist.
2. Use only one. If more than one is needed, then use a master caution plus a word panel for specific danger.
3. Use steady lights. Flashing lights should be reserved for extreme emergencies.
4. When using flashing lights, a flashing rate between 3-10 per second with 4 per second being best.
5. Intensity of light should be twice that of ambient lighting.
6. Locate in the Line of Sight Cone of 30°.
7. Use red lights - because of stereotypic behavior of people.

AUDITORY DISPLAYS

The second most common avenue of communication is audition. The human may receive information through the sensory modality of hearing. Sound perception, masking problems, as well as when to use auditory displays will be covered in this section.

SOUND PERCEPTION

Without going into a lot of detail, audition occurs when the outer ear channels sound waves into the canal to impinge on the eardrum. The eardrum changes the sound waves into mechanical energy and the rest of the ear transmits the sound via the auditory nerves to the brain where perception and discrimination occurs.

MASKING PROBLEMS

According to McCormick and Sanders masking is the amount by which the threshold of audibility of a sound (the masked sound) is raised by the presence of another (masking) sound. Additionally, they state that masking is a condition in which one component of the sound environment reduces the sensitivity of the ear to another component. Masking is determined by measuring the absolute threshold of sound without the masking tone, then measuring the threshold with it. The difference of these two levels is attributed to the masking effect, and masking is central to auditory display discussions.

If auditory displays are to be used and masking may occur then knowledge of a few general principles can prove useful. The greatest masking effect occurs near the frequency of the masking tone and its harmonic overtones. With low intensity, masking tones, the masking occurs near the frequencies around the tone itself. While high intensity masking tones spread from the tone frequency upward. Thus a critical range or zone exists around a primary or center frequency. To reduce masking, consideration of ambient sounds necessary for communication is needed prior to the design of an auditory display.

USE

During the evaluation of auditory displays the HF engineer must address three areas. The first area, detection, is an absolute must. The signal must be heard for a response to occur. Secondly, relative discrimination or differentiating between two or more signals if they are presented close together. Finally, absolute identification of a signal of some class, when only one is presented.

1. Detection of Signals. A sound in the range of 40-50 db above the absolute threshold would normally be detected. Detectability varies somewhat with frequency and duration. If the sound lasts long enough, the ear will "hear" it. This means that if the sound is a pure tone it takes about 200-300 milliseconds to build up and 140 milliseconds to decay. With this in mind auditory signals should last about 30 milliseconds. If less time is used, then increase intensity accordingly. Deatherage, in McCormick, suggests this intensity should be 110 db.

2. Relative Discrimination. This type of discrimination is based on intensity and frequency used in conjunction with JNDs (Just Noticeable Differences).

3. Absolute Identification. This area can be summarized in both dimensions and levels that can be identified.

Dimension	Levels
Intensity (pure tones)	4-5
Frequency	4-7
Duration	2-3
Intensity & Frequency	9

Deatherage (72) in McCormick (82)

RECOMMENDED GUIDELINES

VISUAL DISPLAYS

1. Quantitative Scales

a. Digital or open-window displays are preferable if values remain long enough to read.

b. Fixed-scale, moving-pointer designs are usually preferable to moving-scale, fixed-pointer designs.

c. For long scales, a moving scale with tape on spools behind a panel, or a counter plus a circular scale, have practical advantages over a fixed scale.

d. For values subject to continuous change, display all (or most) of the range used (as with circular or horizontal scale).

e. If two or more items of related information are to be presented, consider an integrated display.

f. The smallest scale unit to be read should be represented on the scale by about 0.05 in or more.

g. Preferably use a marker for each scale unit, unless the scale has to be very small.

h. Use conventional progression systems of 1, 2, 3, 4, etc., unless there is reason to do otherwise, with major markers at 0, 10, 20, etc.

2. Qualitative Scales

a. Preferably use a fixed scale with a moving pointer (to show trends).

b. For groups, use circular scales, and arrange null positions systematically for ease of visual scanning, as at 9 o'clock or 12 o'clock positions.

c. Preferably use extended pointers, and possibly extended lines between scales.

3. Status Indicators

If basic data represent discrete, independent categories, or if basically quantitative data are always used in terms of such categories, use a display that represents each.

4. Signal and Warning Lights

a. Minimum size used must be consistent with luminance and exposure time.

b. With low signal-to-background contrast, red light is more visible.

c. Flash rate of flashing lights of 1 to 10 per second presumably can be detected by people.

5. Representational Displays

a. A moving element (such as an aircraft) should be depicted against a fixed background (as the horizon).

b. Graphic displays that depict trends are read better if they are formed with lines than with bars.

c. Pursuit displays usually are easier for people to use than compensatory displays.

d. Cathode-ray-tube (CRT) displays are most effective when there are seven to nine or more scan lines per mm.

e. In the design of displays of complex configurations (such as traffic routes and wiring diagrams), avoid unnecessary detail and use schematic representation if consistent with uses.

6. Alphanumeric Displays

a. The typography of alphanumeric characters (design, size, contrast, etc.) is especially critical under adverse viewing conditions.

b. Alphanumeric characters should be presented in groups of three or four for optimum short-term memory.

c. Capital letters and numerals used in visual displays are read most accurately (a) when the ratio of stroke width to height is about 1:6 to 1:8 for black on white and somewhat higher (up to 1:10) for white on black, and (b) when the width is at least two-thirds the height.

7. Symbolic Displays

Symbolic displays should be designed on the basis of the following perceptual principles: figure/ground; figure boundaries; closure; simplicity; and unity. In case

the symbols do not clearly represent what they are supposed to represent they should be evaluated experimentally.

AUDITORY DISPLAYS

1. General

   - Compatibility

   - Approximation

   a. Attention-demanding signal: to attract attention and identify a general category of information.

   b. Designation signal: to follow the attention-demanding signal and designate the precise information within the general class indicated above.

   - Dissociability

   - Parsimony

   - Invariance

2. Presentation

   - Avoid extremes of auditory dimensions

   - Establish intensity relative to ambient noise level

   - Use interrupted or variable signals

   - Don't overload the auditory channel

3. Installation

   - Test signals to be used

   - Avoid conflict with previously used signals

   - Facilitate changeover from previous display

McCormick & Sanders
(1982)

SUMMARY

Use as a Display

Auditory	Visual
1. The message is simple.	1. The message is complex.
2. The message is short.	2. The message is long.
3. The message will not be referred to later.	3. The message will be referred to later.
4. The message deals with events in time.	4. The message deals with location in space.
5. The message calls for immediate action.	5. The message does not call for immediate action.
6. The visual system of the person is overburdened.	6. The auditory system of the person is overburdened.
7. The receiving location is too bright or dark-adaptation is necessary.	7. The receiving location is too noisy.
8. The person's job requires him to move about continually.	8. The person's job allows him to remain in one position.

Van Cott & Kinkade
(1972)

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CHAPTER THREE

WORKPLACE DESIGN AND ENVIRONMENT

LESSON OBJECTIVES

1. Be familiar with the general principles of workplace design.

2. Recognize factors related to component placement.

3. Be familiar with the human factor problem areas concerning the environment including atmosphere, motion, illumination, noise, and external conditions.

SUGGESTED ADDITIONAL READING

McCormick (5th ed.) Chapter 12, pp. 342-350, 358-364
Chapter 13, pp. 378-386
Chapter 14, pp. 405-414
Chapter 16, pp. 455-463, 475-477

Van Cott & Kinkade Chapter 9, pp. 381-418

United States Navy Test Pilot School Handout (See Appendix A), pp. 20-25.

WORKPLACE DESIGN

"See you later, dear. I'm going to the Office now." And with that you crawl out of your white bag, zip up your green bag, grab your black bag, and head to your "office." Office? Well, maybe not exactly. But it may help you to envision the cockpit as a very specialized type of office, a workplace in which you sit for long periods of time performing one or two tasks, occasionally interrupted by a phone conversation (intercom) or paperwork that just won't wait (navigation).

As a workplace, a real office has the advantage of being personalized: you can arrange things to fit your personality and your task demands. You aren't so fortunate in this specialized office we call the cockpit. Things are very rigidly arranged for you and it is <u>hoped</u> it meets your needs. Nevertheless, there is a chance you can change things, so it's important to consider some principles of workplace design, for if there is any place that demands peak performance, it's the cockpit. Let's look at the various factors involved in workplace design and see how they apply to <u>your</u> "office."

ARRANGEMENT OF COMPONENTS

A human factors engineer has all kinds of ways to figure out what should go where. Fortunately for you we don't have to go into detail on the specific techniques to do this, but you can look in the references should your thirst for knowledge overwhelm you. For now let's keep our attention focused on some general principles of workspace arrangement.

1. Importance Principle. Common sense dictates that the things which are most important to the performance of the system are the things most easily accessible. As for <u>what's</u> most important, that turns out to be largely a judgment call, though the throttles are certainly more important than the rudder trim switch. Take a look around the cockpit. What is most important to you? Can you see/reach things without moving?

2. Frequency-of-Use Principle. Obviously, if you use something a lot it should be in a convenient location. Items frequently used are more objectively defined than what's most important. After all, it's clear that everyone uses the ADI often while only a few stare at the annunicator light test switch. Often the most used items happen to be the most important so you can satisfy two principles at once if these items are properly placed. Ask yourself: Is there anything in your "office" that's a royal pain to see or operate? Is it because you use it often and it is in a bad location?

3. Functional Principle. This principle states that things which have similar functions should be grouped together. For example, are the radar controls close to the radar? Are all the nav aids grouped in one location? Adherence to this guideline really makes order out of chaos.

4. Sequence-of-Use Principle. As the name states, items should be arranged to take advantage of how they are used. Do the controls and displays conform to the routines you've established for operating or checking them? Does something seem out of sequence when you make a scan of the instruments? Do you jump around during a checklist?

Sometimes these principles may conflict. Van Cott and Kinkade (p. 389) list six priorities to help in designing workplaces:

- First priority: Primary visual tasks - for example, HUD, basic flight instruments.

- Second priority: Primary controls that interact with primary visual tasks - for example, stick/yoke, throttles, speed brake.

- Third priority: Control/display relationships (making the controls and displays work as a unit).

- Fourth priority: Arrangement for elements to be used in sequence - for example, stores management system.

- Fifth priority: Convenient location of elements used frequently - for example, autopilot, comm radios, IFF/SFF.

- Sixth priority: Consistency with other layouts and other systems - check for compatibility.

All this should help you decide which cockpit arrangement is the best (or which arrangement needs alteration because of problems), but there are a few other factors to consider which impact on the arrangement of components.

FACTORS RELATED TO COMPONENT PLACEMENT

Remember, where the components should be placed depends on where you are. If you're stuffed into a seat that is way back in the cockpit and which allows no movement, your assessment of the workplace will be far different than if you are on top of everything. So consider seat design in your thoughts about the cockpit. Does

the seat let you see everything? Does it let you reach what you need to operate? How do the 30° canted and variable geometry seat designs affect your functioning? Do you clear everything without inadvertently touching or activating something? What does the restraint system do to your reach and visibility? Would a smaller or bigger person have any troubles in the cockpit? The combination of seeing and then operating is vitally important; make darn sure you can do both from your normal seated position.

Good seat placement, of course, implies good seat design. There could be a book on this topic along, but all you really need to assess the worth of the seat is your gut reaction after a long mission. The two most important design features of a seat are how it distributes weight and what kind of back support it gives you. One clue to a poorly designed seat is if you shift your posture a lot during a flight. Another clue is if parts of you fall asleep while sitting in one position. Third, check how your back (especially the lower back) feels after an extended period in the cockpit.

Such problems, coupled with the possible reach and visibility problems, have a number of solutions. Making the seat more adjustable - not just up/down, forward/back - is one way. Some auto seats have six-way adjustment, plus inflatable air sacks for lumbar support. Such seats can tailor their fit to your body and are usually far less fatiguing. Additional padding on the seat back and pan, or a wider pan, can also help relieve pressure and discomfort (unfortunately, this may not be possible in ejection seats due to extra acceleration problems).

Another nit noy to consider is where to put your maps and charts and what surface is available to write on. Some cockpits end up with charts clipped all over the panels and consoles and there still isn't enough room.

Lastly, consider the kind of clothes you wear in your office. Once you don some of the Air Force's more sporty clothing, the whole complexion in the cockpit changes, doesn't it? What happens to your reach envelope or manual dexterity when you are sporting the latest in winter gear? How about your visibility in the newest fashion design, the CBN suit? And how comfortable are you in that favorite pilot garb, the poopy suit?

The bottom line is that the cockpit shouldn't be designed for ideal conditions. Rather, it should be designed with degraded difficult conditions in mind; bulky clothing, restricted movement and visibility, long missions, etc. For example, it's easy to fiddle with the F-16 INS panel until you plug in your speed jeans - then the panel becomes very awkward to access. So look at the cockpit from this point of view. Soon all those problem areas will become crystal clear.

ENVIRONMENT

Having some understanding of the general concepts behind workplace design and the mechanics of how and why crew stations are designed as they are, it is important to consider the context in which they are operated. Obviously, you cannot take as much physical stress in a 130 degree cockpit as in a 70 degree cockpit, and the finest instrument designed cannot be read in the vibration and lighting effects caused by penetrating a thunderstorm. In effect, you must take the design out of the pristine confines of the laboratory and either test the system in the actual or simulated environment. These environments can be inside or outside the airplane so we will consider both. Some of the critical areas of concern are: the atmosphere in the cockpit, motion induced problems, illumination requirements, noise, and the external world in which you and the airplane are operating.

ATMOSPHERE

As you would expect, research has shown that performance on both mental and physical tasks is best only in a narrow range of atmospheric conditions. Atmospheric conditions, for our discussion, includes temperature, humidity, and air movement. In dry temperatures above 95°, peak mental performance can be sustained for only an hour or less. High humidity, which prevents the body from effectively cooling itself, further detracts from performance. On the other hand, movement of air from the aircraft ventilation system promotes effective body cooling even at high temperatures, especially in aircraft with a shirt-sleeve environment. Basically, the cooling system of any aircraft should be able to keep the cockpit temperature below 80°, optimally 70°, in its designed primary mission. The air conditioning in the T-37 aircraft works well at altitude, but the aircraft spends considerable time in the traffic pattern where the air conditioner all but doesn't work.

Cold is primarily a problem during preflights, especially for any manual tasks. Fine manipulations requiring an ungloved or thinly-gloved hand increases the problem of conductive cooling. Therefore, you should consider the design of controls which allow manipulation in winter flight gear. Although most heating systems are adequate, distribution of the heat is sometimes a serious problem, e.g., cold footwells. All crew stations and passenger areas should be checked for proper heating.

ATMOSPHERIC CHECKLIST

- Does the heating/cooling system maintain a comfortable temperature range in all phases of flight and, if applicable, ground operations?
- Is the ventilation system sufficient to quickly remove smoke and fumes?
- Does the heating system effectively distribute heat to all areas occupied by people, e.g., footwells, passenger areas, tail-gunner/boom operator positions?
- Are items requiring manipulation in cold weather designed to permit the use of winter-weight gloves?

MOTION

Whether you are vibrating along the desert floor at Red Flag, bumping through some thunderstorms, or earning a 9-g pin, motion effects can seriously degrade your performance. Obviously your manual dexterity is not at its best at 9 g's, so consideration must be given to the location of those components requiring use or actuation in high g flight. Let us concentrate for now on the less obvious design implications of vibration and motion-induced illusions.

There are two major types of vibration: sinusoidal, which occurs at some regular frequency, e.g., vibration from the engines; and random, which is unpredictable, e.g., flying through CAT. Disregarding the physiological effects, vibration has a negative effect on performance. Vibrations with actual accelerations less than 0.2 g's can decrease performance on tracking tasks as much as 40%, especially during vertical vibration. However, sidemounted sticks with armrests (like the F-16) can reduce vibration-induced error by as much as 50%. Inadequately damped display/control panels will affect visual and manipulative tasks. The amount of visual task impairment is based not only on the type and severity of the vibration (worst case: 10 to 25 Hz), but also on the letter/display size and the density of the display to be read. Vibration also affects the overall subjective comfort of crew members and passengers. Along with anxiety, past experiences, and expectations, vibration can strongly influence motion sickness occurrence, particularly at crew/passenger stations without an outside view.

The motion of the aircraft through space also combines with design problems in equipment location that can result in motion-induced illusions. All of the illusions discussed in AFM 51-37 can be experienced if components requiring actuation during

IFR or low outside visibility flight are located so as to cause turning or tilting head/body movements (e.g., the IFF interrogator in the F-15). With your experience in the cockpit and perhaps Vertigon training, you are well aware of the problem areas in the planes that you have flown and should look for similar design problems in the aircraft you test. Examples: (1) A Tacan or IFF/SIF that is located at the bottom of the center pedestal that would require the pilot to tilt his head. In an established turn or circling maneuver this may result in the Coriolos illusion (rolling sensation). (2) Landing lights that remain illuminated until fully retracted causing a pitch-up sensation. This should add to the oculogravic illusion (pitch up or down sensation from acceleration) already present during takeoff.

MOTION CHECKLIST

- Are critical instruments/displays readable in typical vibration conditions (consider damping adequacy, enlarging size/numeration of display, etc)?
- Are critical components usable/reachable in high g flight and can they be accurately manipulated without over or under control?
- Are devices or displays that must be used during low visibility conditions located where motion-induced illusions will result?

ILLUMINATION

Because each cockpit task requires a different amount of illumination and because the amount of ambient lighting varies from brilliant sunshine to total darkness, correct illumination of instrumentation and warning lights presents a complex problem. From the operator's point of view, if you can't see it or if it does not quickly attract your attention (e.g., the master caution light) it needs to be changed. Not so obvious, however, are the annoyance problems which you learn to live with but cause years of misery for lots of pilots. All placards, warning and caution lights, progress display lights, and instruments should be easy to read in all ambient lighting conditions. Minimum lighting, combined with high contrast and large numeration displays, is desirable because it minimizes the decrement in dark-adapted vision for outside cockpit vigilance. Additionally, minimum lighting helps to prevent the problem of glare off the glass faces of the instruments and the canopy/windscreen. Annunciator lights, master caution/warning lights, etc., must attract attention immediately but have a dimming feature for low light conditions so as not to become a distraction. Clearly, certain warning lights, in order to be seen in bright sunlight, would have to be ridiculously bright and instead may be to be tied to an auditory alarm. No light

at the crew station should shine into the operator's eyes. Such direct light, as well as an undimmable lights, cause a phenomenon known as phototropism, a tendency for the eyes to turn towards a light, an unacceptable cockpit distraction. Often, due to the necessity of reducing the number of controls for space considerations, one rheostat or switch may control a group of instruments. This problem is especially prevalent in retrofits where the new instrument/display has considerably different lighting than the rest resulting in an inability to read the new instrument, if it is dim, or all the surrounding instruments, if it is bright.

The bottom line for the user is: Can I see what I need to see when I need to see it? If you can adjust the lighting to your satisfaction (without resorting to masking tape), have enough control over the lighting, and have eliminated the annoyances created by lighting, then you will be close to optimizing crew station illumination.

ILLUMINATION CHECKLIST

- Is there enough lighting on all displays, placards, and instruments to be clearly seen?
- Do emergency/caution/annunciator lights attract attention day or night and can they be dimmed for night use?
- Do instrument lights shine directly at crew station occupants?
- Do cockpit lights create reflections on the canopy/windscreen detracting from outside visibility?
- Do all lights controlled by a single rheostat or switch have equal intensity, especially retrofits?
- Is there a distracting glare off instrument glass or panels?
- Can you control the lighting, e.g., distribution, quantity, to your satisfaction?

NOISE AND SPEECH COMMUNICATIONS

Let's face it - you can't reach over and turn the engines off just because they are too noisy. Nor can you put in earplugs to get rid of the noise and expect to hear your radio as well as before. But you may find some creative solution to the noise and communications problem, so we'll outline a few things in this section to let you better understand the situation.

For our purposes let's define noise as unwanted sounds, sounds which interfere with your detection of beeps, buzzers, and speech. You get noise mainly from the engines, of course, though there is some background noise on the radio and from those around you in the cockpit. While such noises can grate on your nerves or even partially destroy your hearing (such as in a Tweet--unprotected, your ears will eventually lose certain frequencies), the general effects of noise are to make it hard to hear the signals you need to hear. It's a difficult problem to solve: if you protect your ears from the noise you can barely hear your radio and may never hear alarms.

Part of the problem can be dealt with easily just by controlling the side chatter in the airplane. The rest of the problem requires more innovative solutions. One example is cell call on HF radios: you can turn off the noise until the radio is used. But that's not a cure-all by any means. Think of the various problems and perhaps a solution will be apparent. Do you install better radios, maybe with a Dolby system? Do you simply boost the gain of the existing radio? Should you pair a flashing light with each alarm? Keep in mind the bottom line is again how to improve performance in a not-so-ideal environment.

THE REAL WORLD VERSUS THE INTER-AIRCRAFT ENVIRONMENT

In my tip-of-the-iceberg coverage of the environmental concerns, I have left out some considerations of the outside environment in which you must operate. In many instances, the engineers can provide systems and displays far in excess of what the operator can use. The outside environment where the aircraft flies dictates, to a large extent, what can be put in the cockpit. Weather may require anti-ice equipment, may require a system to automatically brighten all cockpit lights to combat the effects of flash blindness due to lightning, or may require the ability to dim cockpit lights. On the other hand, formation flight, combat situations, or low-level operations may make an excellent, but time-consuming-to-read, display useless to an aircrew member. In evaluating any aircraft environmental/workplace design, the external environment in which the system is expected to operate will be a major controlling factor in the design evaluation.

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CHAPTER FOUR

TECHNOLOGY AND AUTOMATION

LESSON OBJECTIVES

1. Define automation and list the three man/machine tasks that lend themselves to automation techniques.

2. List and give an example of the limitations of the human operator when placed in an automated environment.

3. Explain how Computer Generated Imagery Information Displays can affect pilot tasking and workload.

SUGGESTED ADDITIONAL READING

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TECHNOLOGY AND AUTOMATION

Modern combat aircraft of today have evolved into highly complex and competent weapons systems that have the capability to fly under extremely difficult conditions while performing timely and highly accurate weapons delivery. These advances in aircraft capabilities were made possible by the tremendous technological advances that have occurred over the past two decades and are still occurring at an alarming rate.

Another consequence of these technological advances is the threat environment in which these aircraft must fly and accomplish their highly complex missions. Technology has allowed the air-to-air and surface-to-air threats to keep pace with the acquisition, detection and destruction of these advanced aircraft.

The key to providing these aircraft and threat systems with higher levels of performance has been the technological advances in the areas of systems automation and information display presentations to the operators. The term "automation" is subject to several diverse and varied interpretations. Automation can be used to describe the control of a single function or operation such as a simple on-off mechanism, or it can be interpreted as the integration and concurrent display of data from numerous sources to an operator for interpretation and control. An example of this is the advanced display systems used in the cockpits of modern fighter aircraft such as the F-18 and F-5G. Automation can also be used to describe the control of complex processes and systems in which the automated control can replace or augment some of the functions required of the human operator, such as monitoring tasks and decisionmaking functions. Automation has been applied to the monitoring and control of engine operations and malfunctions to electrical and hydraulic systems operations and to the improved navigational and weapons systems of modern aircraft.

THE AIR FORCE AND AUTOMATION

In a report on automation in combat aircraft, the Air Force Studies Board (1980), defined automation "as those processes by which essential functions can be performed with partial, intermittent, or no intervention by the pilot." In their report, the term automation was used to describe any effort to move the cognitive processes of flying the aircraft and managing its weapons from the pilot or aircrew to a computer-dominated system. An example of the application of this automation technology can be seen in several of our newer aircraft. The B-1B bomber has a built-in central integrated test system that monitors all of the aircraft's subsystems and advises the

crew if there's a failure. The aircraft also has an automatic terrain-following capability that allows the pilot to fly completely hands off. This allows the pilot to accomplish more in terms of stress management when dealing with in-flight emergencies or with wartime threats. Another example of the use of advanced technology in maximizing the number of functions that can be performed by the pilot during stressful situations has been demonstrated by the F-5G Tigershark. The F-5G has a cockpit designed around the Hands-On Stick and Throttle (HOSAT). HOSAT will allow the pilot to "navigate, locate targets and deliver weapons without taking his hands off the flight controls, because avionics selection and weapons delivery switches are located on the stick and throttle." (Defense Electronics, 1982, p. 162).

HOW TO AUTOMATE THE MAN/MACHINE SYSTEM

Automation therefore can be defined as the processes by which essential functions can be performed with partial, intermittent, or no intervention from the operator. The Air Force Studies Board identified three dimensions along which automation could be applied.

AUTOMATION OF CONTROL TASKS

An Aircraft's control and display systems should be designed to be compatible with the pilot's mental representations of the tasks to be performed. This should lead to a reduction in pilot's workload and error rate because a compatible (automated) system will reduce the number of mental operations required to perform a task. Automation could also reduce peak task demands by automating task activities or by shifting parts of the task to more task-free times in the mission.

AUTOMATION OF MONITORING TASKS

Pilots normally prefer operationally-relevant information and will most likely accept monitoring systems that give them very specific information about malfunctions. A display showing "Overtemp" is less useful than one stating "Rt. Eng. on Fire" which is less useful than one that displays all capabilities lost or retained. The danger is that diagnostic information and following recommended action may be in error. Automation could also allow the pilot to query the malfunction indication to verify the condition or obtain further information concerning the actual extent of the emergency.

AUTOMATION OF PLANNING AND TACTICAL TASKS

Automation will assist the pilot in the planning stages by allowing vast amounts of

information concerning weapons, threats, sun angles, low level routes, etc. to be pre-programmed which will greatly assist the pilot during actual flight conditions. The big S.A. (Situational Awareness) could be greatly enhanced by automation by combining inputs from the aircraft's sensor systems, known threats, weapons capabilities, etc. and supplying this data in near real time to aid the decision-making process.

THE HUMAN OPERATOR

The only system that has not changed significantly with the advances in technology is the human operator. The pilot of any aircraft is limited in his ability to assimilate and perform the tasks. The pilot is often not able to effectively handle the increased workload associated with the operation of today's complex, fast, maneuverable, and highly mechanized aircraft. It is hopeful that the technological advances in automation will effectively reduce the workload and overcome the limitations of the human operator as part of the overall man/machine system.

Any attempt to automate the activities within a combat aircraft must take into account the human operator as the most crucial component of the overall system. The allocation of tasks between the pilot and systems/equipment must be done in the context of the capabilities and limitations of the human operator to include perceptual skills, information processing capabilities, and physiological restrictions. Many of these capabilities and limitations have been discussed in previous chapters. The Air Force Studies Board defined several different, but related, sources of "pilot workload for which some application of automation may be beneficial:

1. Perceptual saturation
2. Concurrently performed tasks
3. Time-line compression
4. Pilot bandwidth limitations
5. Small-scale, routine operations

Each of these sources of workload can negatively affect pilot performance. Automation, when properly applied, may help mitigate these performance decrements.

PERCEPTUAL SATURATION

Since the human pilot is a serial processor, he takes an appreciable time to react to

critical events especially if they occur simultaneously with several other critical events. An example would be the launching of several missile threats at the pilots' aircraft. The human pilot would have great difficulty in keeping track of these numerous threats.

CONCURRENTLY PERFORMED TASKS

There are many mission phases that will require the human pilot to operate several pieces of equipment at the same time to effectively accomplish his mission. The number and type of these concurrently performed operations can greatly influence the workload on the pilot. Studies analyzed by the Air Force Studies Board show that the systems that interact with others are flight controls, threat warning and countermeasures, navigation, target sensing and acquisition, external data, and weapons delivery. Automation that produced a reduction in the number of these concurrently performed tasks could effectively reduce pilot workload.

TIMELINE COMPRESSION

Today's aircraft have the ability to travel at extremely high rates of speed which greatly compress the time a pilot has for analysis, judgment and follow-on action. In a typical head-on encounter between two high performance aircraft closing at 2,000 feet per second, a pilot only has 2-3 seconds in which to identify and communicate the presence of the enemy aircraft, acquire, lock and track the enemy with his weapons system, shoot the weapon and plan his next move. The addition of automated systems to eliminate or reduce the workload associated with these time-compression encounters will greatly benefit the pilot.

PILOT BANDWIDTH LIMITATIONS

The concept of pilot bandwidth limitations refers to the fact that humans are limited in the rate at which they can perform manual tracking. Humans normally need on the order of one-half second to make a control adjustment and are therefore incapable of controlling an aircraft that requires more than two corrections per second. The frequency of control inputs in several newer aircraft such as the F-16, far exceed this control requirement and as such computers and automated systems must be applied to allow effective human control of the aircraft.

SMALL-SCALE ROUTINE OPERATIONS

There are currently many operations performed in a cockpit that require numerous

small steps for effective completion. These tasks are time-consuming, error prone and impose heavy memory loads and pilots that could be reduced with the proper application of automation and advanced technology.

The Air Force board also pointed out that automation is not the only means available for achieving a reduction in workload. Alternatives such as improved training programs and revised flight procedures may provide preferred choices depending on the situation.

ADVANCED COCKPIT CONCEPTS

DISPLAYS

One major thrust in the attempt to automate the aircraft has been the visual display systems used to present information to the pilot. Yesterday's round-dial cockpit presentations are slowly giving way to electro-optical displays which use computer-generated imagery formats. It has been the evaluation of technology that has considerably altered and extended the human sensory and motor ranges far past their normal capabilities. At the same time, these computer-generated display systems have imposed time-critical overload conditions on the pilot due to the rapid availability and volume of data. It has therefore become essential that display systems be developed to provide the pilot information acquisition, process, and transmittal in the most rapid, accurate, and reliable manner possible. The application of these concepts can be seen in aircraft such as the F-14, F-15, F-16, and F-18 fighter aircraft. It is obvious that the technology to design and provide this data to the aircrews is already here; the challenge will be to provide it in a form which is usable by the aircrew members.

ARTIFICIAL INTELLIGENCE

One of the futuristic concepts that will enhance cockpit automation will be the use of artificial intelligence to handle some of the more straight-forward decision-making tasks that face the operator. One of the more useful applications of artificial intelligence could be in the analysis and initial reaction to aircraft malfunctions. As an example, if an aircraft should experience a malfunction such as an electrical failure of one of the engine-driven generators, and this malfunction should occur during a high task-loaded mission segment, the "intelligent" computer system could analyze the malfunction, divert critical systems over to the functioning electrical generator to ensure that the aircraft maintains its combat capability, reduce any unnecessary loads

on the electrical system then inform the pilot of the steps taken and of the steps needed to be accomplished, time permitting. These "intelligent" systems would accomplish all but the most critical steps which would be left up to the option of the pilot.

VOICE

Voice activation of aircraft systems could also reduce workload and is currently being used in two major ways in fighter aircraft. Voice can be used as an additional information system to warn or inform the pilot of conditions that exist within the aircraft's systems. The F-15 currently uses this approach for low altitude warning and for emergency warning. Voice commands will also allow the pilot to actually activate aircraft systems by voice command. This approach is currently being demonstrated in the F-16 (AFTI) aircraft to activate radio changes and navigational aids within the cockpit with a totally hands-off capability. There are many problems yet to resolve with the use of voice activation of aircraft systems but technology promises to rapidly solve them.

BIOCYBERNETICS

Biocybernetics is basically defined as the physiological sensors and associated computer software that is used to monitor and assess the internal mental and physical states of a human operator. An analysis of brainwave patterns, especially the spike in the pattern known as the P-300 component, can be utilized to determine when someone is processing information and at what point this processing is concluded (Figure 1). In terms of aircraft application, what is foreseen is that the aircrew member will be monitored continuously during a mission by using non-intrusive sensors that have been implanted in their flying clothing and helmets. Through these non-intrusive sensors, "a pattern of information processing load, physiological workload, and motor control behavior for each flight segment could be established." (Reising, 1979, p. 206). Thus the onboard computer will be able to analyze EEG data and determine if:

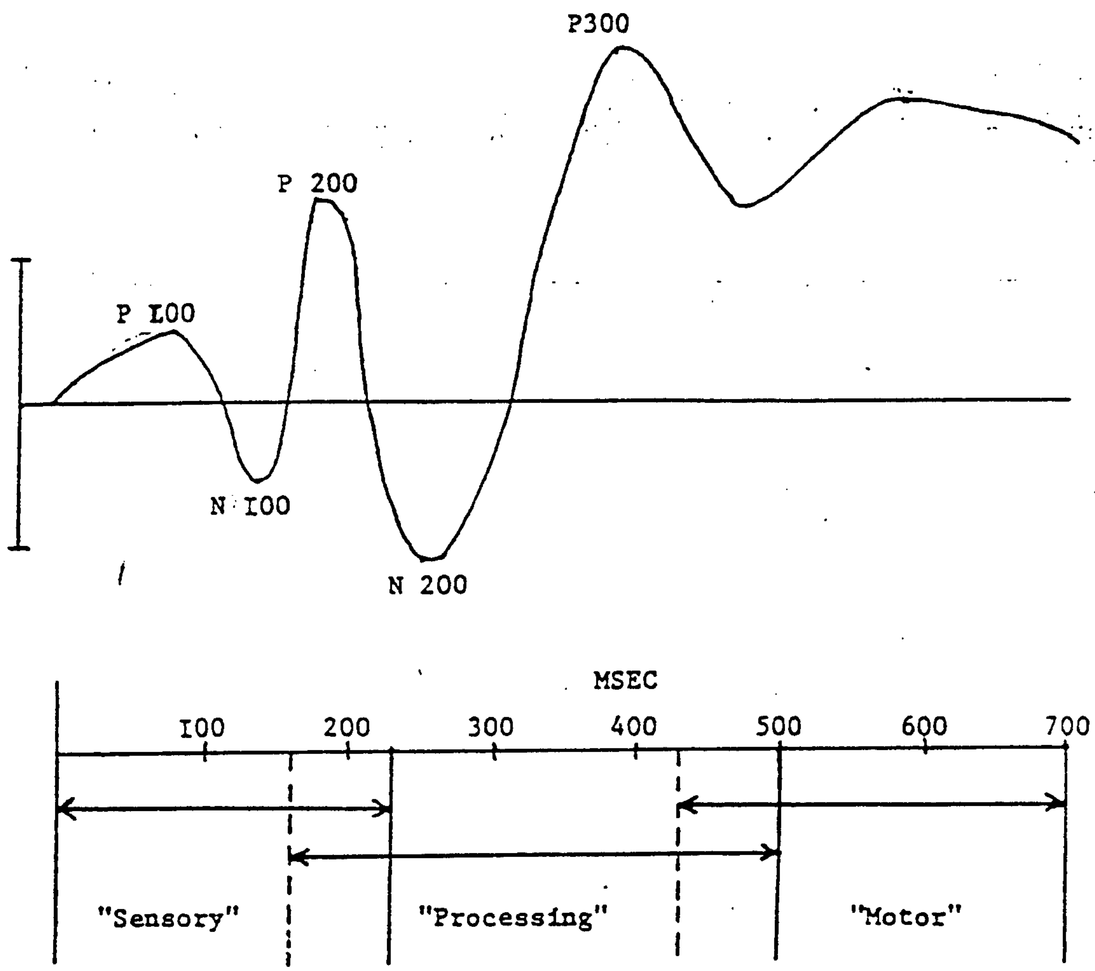

FIGURE I. P-300 BRAINWAVE PATTERNS

1. The pilot is inattentive.

2. The pilot does not process visual and auditory information.

3. The pilot is task saturated to the extent that no further duties can be accepted.

4. The pilot lacks confidence in a recently made decision.

In addition, a template of the operator's behavior patterns can be developed that can be used to control or augment existing aircraft systems. For example, the biocybernetic sensors might indicate that the aircrew's behavior is out of bounds from normal patterns (e.g., pilot injured), and this deviation could be fed into the computer software which would make the decision to either automatically take over a system or function from the operator or at least advise him that he software will take over unless the operator overrides the system. Additional actions the on-board computer might take could include:

1. A redistribution of task responsibilities.

2. Reducing the complexity or "decluttering" information displays.

3. Furnishing remedial checklists.

AUTOMATION PROBLEMS

The application of advanced technologies and automation have not always been successful. Several pitfalls have been encountered when automation was applied without a thorough understanding of the effects and consequences that might occur under actual user situations.

1. The addition of computers to aircraft systems has caused a reliability and maintenance problem that requires extra effort and training on the part of maintenance personnel and pilots. The adverse effects of automation in terms of increased complexity must be fully explored.

2. Designers and engineers alike must also be aware of the unnecessary use of automation. Automation must be applied in a manner that will enhance the performance of the pilot by reducing the workload in high task situations.

3. Pilot acceptance of an automated system is also very critical. If a pilot feels that an automated system is useless of unreliable, he will probably not use it.

4. On the other hand, an unanticipated consequence of automation has been the loss of manual flying proficiency that has caused a need for retraining in some instances.

5. Other problems, such as increased training requirements, failure modes in the automated systems, and inflexibility or unmodifiability of a new system all must be critically analyzed so that their effect on pilot workload and performance can be understood.

SUMMARY

The guidelines for the automation of fighter cockpits is not complete. Confidence in the application of advanced technological systems will only occur when their overall performance is determined. Designers must ensure that this application of technology actually frees the pilots from a host of monitoring tasks, memory and number-crunching exercises, and the constant attention to precise and sequential duties that now hinder his activities. The "stick and rudder" pilot is slowly becoming a vision of the past. The pilot of the future will be a decision maker and an information processor that will have to be prepared to make very complex decisions in a tactical warfare environment. The application of technology and automation must be devoted to aiding the pilot in this environment.

CHAPTER FIVE

OPERATOR WORKLOAD

In designing and developing complex man-machine systems, system designers and evaluators need to determine if trained operators can adequately perform required tasks to achieve successful system performance. One aspect of this determination utilizes a concept referred to as operator workload. In its most basic usage, operator workload is simply how hard a person must work to satisfy a given set of task demands. These demands may be characterized as both physical and mental, although the mental demands are far harder to pin down and measure. With respect to the primarily mental demands of tasks in complex systems, the system designer ensures that a population of operators can control and maintain the system configuration being proposed, both under normal and emergency situations. That is, he must determine that operator workload is not excessive for a given design, for if it is, system failure will likely follow.

Although the concept of mental workload can now be found in theories developed by academically oriented psychologists, physiologists, and engineers, it received its early impetus from specialists attempting to solve the applied problems of man-machine interface. Their concern for practical approaches to assessing mental workload helped proliferate a number of assessment methods but at the same time proliferated definitions of the workload concept. To deal with this loose and very intuitive concept--which implies the extent to which an operator is "mentally occupied"--numerous and independent definitions appeared. For example, mental work-load was and still can be defined by the time tasks require divided by the time available, a decrease in heart rate variability as the decision making demands of a task increase, the number and level of inputs to an operator determined by task analysis, the perceived magnitude of fatigue, tension, and difficulty gathered from a questionnaire, and the spare mental capacity or reserve attention of an occupied operator as determined by performance on a secondary task. As diverse as these approaches are, they represent only a small subset of the techniques that have been employed to assess mental workload.

To impose some order in this research area, several measurement classification systems have been proposed (Gartner & Murphy, 1976; Sheridan & Stassen, 1979), all of which are fairly similar. Starting with a general definition of workload, such as "an integrative concept for evaluation of the effects on the human operator associated with the multiple stresses occurring within man-machine environments" (Jahns, 1973), these systems point out that workload has different components or means different things in different contexts. For Jahns, workload has three related components, namely input load, operator effort, and work results. Using this component approach, Johannson (1979) argues that measures which gauge operator effort in response to system inputs provide the most meaningful picture of workload, especially mental workload. Sheridan and Stassen (1979) list six specific definitions of workload which dictate the appropriate measurement techniques: 1) what physical task is assigned; 2) what criterion is to be followed; 3) the information processing the operator actually performs; 4) energy expended by the operator; 5) what emotional stresses the operator experiences; and 6) the overall system performance which finally results. The latter definition, Sheridan and Stassen argue, is not properly a definition of workload, although some investigators have treated it as such. As many researchers have observed, an operator may achieve equal performance with two system configurations, yet work twice as hard on one as the other.

In addition to these classification systems, workload conferences (Moray, 1979), reviews (Gartner & Murphy, 1976) and guides (Wierwille & Williges,, 1978) have all acknowledged this multitude of definitions and measures and have attempted to pull the existing concepts together in some coherent fashion. At a recent NATO symposium on the theory and measurement of mental workload, Johannsen (1979) called for the attendees (psychologists, engineers, physiologists) to reach a consensus on a definition of workload and find valid relationships between measurement techniques as they relate to the workload concept. Failure to achieve these goals is evident from the papers presented by applied researchers. In summarizing the attitudes of the applied researchers, Hopkin (1979) noted that none of the techniques approached general acceptance as a standard measure of mental workload in applied settings since they were either impractical or hard to interpret. Further, Hopkin stated that "theory has not produced an umbrella technique to partition, predict, or measure the multitude of variables in an operational field problem." With no universally acceptable definition of mental workload available, system designers must start with operational definitions and methodologies that may have to be modified as system definition progresses (Hopkin, 1979).

This failure to find the universal definition of mental workload can be traced to conflicting experimental results where more than one measurement approach has been employed. In one of the few studies that have purposefully compared several measurement techniques, Hicks and Wierwille (1979) found that subjective ratings and certain primary task performance measures could discriminate among three levels of workload in a driving simulator. The techniques of visual occlusion, heart rate variability, and secondary task performance, however, produced results unrelated to workload level. Using pilots and copilots, Gunning (1978) examined the workload levels associated with different phases of an airdrop segment of the mission but analysis of the time estimation data revealed no differences between conditions. Krebs, Wingert, and Cunningham (1977) investigated the relationships between eye behavior, subjective ratings, and pilot workload when a simulated aircraft landing task was manipulated in difficulty. Although the subjective ratings tended to be associated with manipulations of task difficulty, no parameter of eye behavior exhibited such a trend.

Dozens of such studies exist, yet each insensitive technique mentioned above--visual occlusion, heart rate variability, secondary task analysis, time estimation, and eye behavior--have all been shown in other single method studies to be sensitive to task difficulty manipulations (see Wierwille & Williges, 1978, for a list of 400 references covering no less than 28 workload techniques that have been employed).

Two responses to this state of affairs are evident. The first concentrates on how the methods are used. Much inconsistency is attributed to crude and inappropriate use of a technique or poor scoring. The complexities of secondary task usage are now receiving a great deal of attention as are the use of various physiological measures. This kind of information produces prescriptions of how techniques should be used (Wierwille & Williges, 1978).

The second response is more basic, and in the long run, more fruitful. It asks the question, "Do we measure what we want to measure with the usual measure of mental load"?, (Sanders, 1979). This approach deals with the data inconsistency mentioned above by acknowledging that operator workload has many components or aspects to it. This view accepts the fact that some techniques may produce evidence of changed workload when task difficulty is apparently manipulated while others may not. This simply means that no one number (result from a specific technique)

represents the total workload of a task, and tasks cannot be rank ordered by difficulty with these single numbers. Thus, the workload of a task is not a single quantity but some combination of quantities put together in as yet some undetermined way.

As researchers and designers wrestle with these problems of workload measurement, your concern with workload will be much narrower. As a test pilot, you will be asked for your opinions or ratings of the workload induced by different system configurations during different mission segments. Most assuredly, these opinions are important, but you should be aware that opinion data in and of itself can have problems. Researchers have classified operator opinions and ratings of workload as "subjective measures of workload", and the remainder of this chapter discusses some of the findings on subjective measures.

Reviews of workload assessment techniques consistently conclude that operator opinions are valuable indices of mental workload (Moray, 1979; Wierwille & Williges, 1978). The quote from Gartner and Murphy (1976) that "the pilot's direct perception or estimation of his feelings, exertion, or condition may provide the most sensitive and reliable indicators" of workload, is often repeated or paraphrased. Indeed, the last ten years have produced nearly repeated or paraphrased. Indeed, the last ten years have produced nearly 100 published studies in which operator opinions of workload, both direct and otherwise, have been reported. The opinions gathered, however, are almost always related directly to the equipment configuration under evaluation and not to any general task characteristics that produce feelings of mental load. Thus, situation-specific opinions of mental workload are measures typically gathered in addition to the more "scientific" workload measures.

For example, Spady (1978) looked at instrument scanning patterns of pilots during instrument landing approaches in two different system configurations under two conditions of atmospheric turbulence. The scan patterns differed reliably and pilots' opinions concerning instrument usage were found to be in agreement for the most important instruments.

Despite the frequency and utility of operator opinions, reviews of subjective assessments note that the rating scales used are often just thrown together. Everyone has completed surveys (e.g., rate your agreement on a 1-7 scale with some statement) so everyone thinks they can write surveys. That turn out not to be the case. Further, psychologists have developed statistical techniques to evaluate the worth of rating scales and surveys, and these are almost never applied to the scales developed to measure subjective workload. In addition, people who complete rating scales can be

biased. For example, previous experience with a system may cause an operator to underestimate the workload of a new but similar system. We know that increased physical effort can make it difficult for an operator to rate only the mental effort required in a task, but attempts to separate the two are not done. It has also been argued that during periods of intense concentration when mental workload should be very high, an operator may be least aware of the amount of effort he is investing in task performance. To these points can be added another serious flaw. Often the assessed workload concept is never defined for the rater, apparently because it is so "obvious" what is desired. He is just asked to rate the level of workload or acceptability of workload for a particular system configuration.

Two exceptions to this state of affairs can be noted. With respect to manual control tasks, mental load has repeatedly been measured on scales developed by Cooper and Harper. These scales were developed to measure the handling characteristics of aircraft by using the subjective reports of these pilots. The scales are well established and validated, having been in use for over 20 years. The C-H scale can be regarded as a useful and reliable instrument for determining the "fly-ability" of aircraft. However, manual control is only one aspect of flying. In many cases, it is a relatively small part of the task; activities such as systems management and decision making require far more time and effort. Therefore, most psychologists agree that Cooper-Harper ratings do not tell the whole mental workload story.

A second exception is a relatively new technique for measuring subjective workload. This technique was developed at the Aerospace Medical Research Laboratory at Wright-Patterson AFB, Ohio and has been given the acronym SWAT - Subjective Workload Assessment Technique. In SWAT, subjective workload is defined as being composed of three dimensions: 1) time load; 2) mental effort load; and 3) stress load. Each dimension is measured by a simple three-point scale with verbal descriptions for each point. A technique called conjoint measurement permits the three dimensions to be combined into one overall scale of subjective workload. To produce the mathematical rules that combine the three dimensions, operators must first rank order the subjective workload associated with the 27 possible outcomes (3 dimensions, 3 points per dimension). Operators then perform tasks, rate the tasks on time, effort, and stress load, and the conjoint measurement produces overall ratings. To date, SWAT has been successfully used with subjects doing tasks in laboratories and pilots flying several types of aircraft in several mission profiles.

In conclusion, workload is a concept that has many definitions and measures. Many times these measures produce conflicting results when designers and researchers attempt to measure workload. Even when gathering only subjective workload data, we find that many problems can arise. Until many issues can be resolved, you, the test pilot, still provide one of the best indices of workload in the aircraft.

APPENDIX A

UNITED STATES NAVY TEST PILOT SCHOOL

HUMAN FACTORS HANDOUT

NO AUTHOR

NO DATE

HUMAN FACTORS CONCEPTS

AND DESIGN PRINCIPLES

INTRODUCTION

PURPOSE OF CREW STATION EVALUATION

One of the reasons for conducting a crew station evaluation at TPS is to acquaint the student with the human factors design requirements as related to aircraft testing. The crew station is the focal point of the man-machine interface; therefore, it is the area which should receive primary human factors design emphasis. In the past, however, many crew stations received little or no emphasis concerning human accommodation or compatibility. Quite often not until all items had been assembled into a functional crew station were human factors design violations made known. Under these conditions, due primarily to monetary constraints it is not feasible to make the necessary design changes. However, because of the established relationship between human factors design deficiencies and known aircraft mishaps, accidents, and reduced weapon system performance there has been, in recent years, an added emphasis to include human factors principles in crew station design.

HUMAN FACTORS ENGINEERING

It is the responsibility of the human factors engineer to insure that the machine has been designed to adapt to the man. He attempts to do this by applying his knowledge of human behavior to the design and structuring of machines and work environments. While the engineering capabilities of modern technology have often been astonishing, it is also true that in many instances an engineer's dream has been a nightmare for the human operator. This situation occurred in World War II when machinery was manufactured that required too many arms, legs and in some cases too many heads for a man to operate such equipment. As a result human errors mounted and were responsible for gross malfunctions, with sometimes devastating results. Thus, engineers were joined by psychologists, physiologists, and other professionals in an attempt to design hardware subsystems so that human abilities could be complemented and human limitations compensated for.

The elimination of human error in systems in which man and machine must interact requires first that the designer understand which task must be performed by the operator, and, second, that he understand the human functions that such tasks entail. Equipped with knowledge of what the human operator is really doing in interaction with a machine, the engineer can then adequately and intelligently design the particular features of the system that require interaction between man and machine.

The goals of human factors engineering are twofold: they involve the design of machines and work environments that will 1) permit optimal human functioning in the kinds of tasks performed by the operator; and (2) at the same time provide maximum system efficiency in attaining the goals for which the system was conceived.

OPERATOR'S ROLE IN HUMAN ENGINEERING

The human factors engineer cannot achieve these goals alone. He cannot be behavioral scientist, design engineer and qualified operator for each system he evaluates. Due to the latter the human factors engineers must coordinate with the system operator in order to obtain inputs on the man-machine compatibility. Especially important is information related to the varied operational conditions. In order for the operator to provide accurate and reliable data for the human factors engineer, he must be to some extent, human factors oriented. That is, he must be familiar with the basic human factors engineering design principles, and with the most commonly encountered human engineering design errors.

MAN-MACHINE SYSTEM CONCEPTS

In general, the human factors engineer is concerned with everything at the crew station the operator sees and touches. He is concerned with everything perceived because this is how the operator obtains information on the status of the system. Based on the information received from the various displays, the operator reacts to the situation by manipulating required controls. It is the inclusion of the man into the system loop that gives use to the concept of man-machine interface. The efficiency by which displays provide the needed information on system status and the efficiency by which controls allow the operator to manipulate the systems gives rise to the concept of man-machine compatibility. It is this latter concept that the human factors engineer attempts to maximize. Through the design of what the operator sees (displays) and touches (controls) the human factors engineer seeks to achieve maximum system effectiveness.

HUMAN ENGINEERING DESIGN DEFICIENCY EXAMPLES

To illustrate more clearly, the meaning of man-machine compatibility and its relationship to human engineering design deficiencies two examples are provided.

The first example involves spatial disorientation, or vertigo. It is difficult to prove because it has no relation to altitude or failures of equipment. The occult nature of this abnormally taxes the ingenuity of all investigators of aircraft accidents; however, in the late 1950's a review of fatal jet aircraft accidents of undetermined causes frequently revealed the following strange pattern:

The aircraft which were involved were always jet fighters or interceptors.

The pilots were usually young, at least inexperienced.

The stage of flight was usually in the landing or approach pattern, but sometimes shortly after take-off.

The altitude was relatively low, usually about 2000 feet.

The aircraft speed was usually about 350 knots.

The aircraft was often in a procedural turn.

The instrument flying conditions prevailed with minimum visibility, or it was a black night.

The pilot was requested to change radio channels or modes, or was in a position where routine channel changes should have been made.

After the pilot had been requested to change channels, he replied with terrific velocity and often times in a near-vertical attitude.

Almost immediately thereafter, the aircraft struck the ground with terrific velocity and often times in a near-vertical attitude.

Detailed investigation reveled that the radio channel selector was set far to the rear of the right console in practically all aircraft involved. This made it necessary for the pilot to change hands on the stick and turn his head down and to the right. Therefore, he not only lost monitorship of his essential instruments, but was in an ideal position to establish the most vicious form of vertigo caused by coriolis force.

The prevalence of accidents of this nature was confirmed by further review which revealed that during the two proceeding years there were twenty-four instances wherein the last statement of the pilot before entering a high speed dive to the earth was that he was changing radio channels. How many others crashed fatally under similar circumstances without announcing this move will never be known. However, the evidence was sufficient, and the radio channel selectors were moved to a more accessible location. Accidents of this type virtually ceased.

The above example illustrates clearly how a design deficiency can lead to a serious aircraft accident. But just as important it emphasizes the subtle nature of most human engineering design problems. That is, under different conditions such as non-IFR and with experienced instrument pilots there would most likely not have been an aircraft accident. For this reason, it is essential that a crew station evaluation should reflect to the greatest extent possible, the varied operational conditions that would be encountered. The next example illustrates one of the most common human engineering problems. The problem of inadvertent control actuation.

> On the third simulated bombing at 500 feet and .72 MACH, the pilot attempted to turn his LABS CAGE/UNCAGE switch to the UNCAGE position. A loud noise and heavy vibration were noted and the pilot pulled up to gain altitude, believing the difficulty to be impending engine failure. He then noted that the landing gear handle was partially down, and that the landing gear indicator showed the nose gear to be down and locked, and the main gear unsafe. Upon slowing to 200 knots, the pilot placed the landing gear handle in the DOWN position. The port main gear then indicated down and locked, but the starboard gear still indicated unsafe. The pilot notified the flight leader of his difficulty and effected a rendezvous. A visual check was made and all gear appeared to be down and locked, although a hydraulic leak was apparent. Upon notifying the tower and obtaining clearance for a straight-in approach, the pilot made a normal landing at 140 knots with flaps. Rollout speed was 100 knots prior to engaging the arresting gear.

Investigation revealed that the landing gear handle was inadvertently moved at excessive speed. Movement of the landing gear handle was pilot induced but was caused by poor human engineering design.

In the first example, it was necessarily due to the severe nature of the deficiency to modify the channel selector location. This procedure is extremely costly. For example, just to change one label on an operational aircraft costs in excess of a million dollars once retooling, publication changes, and other costs are included. In the example of inadvertent actuation of the wrong control, it is possible to make operational personnel aware of the problem through wide spread dissemination of the information and to have squadrons conduct briefings on the possibility of inadvertent gear actuation. Although this is not the ideal solution, it at least can reduce the possibility of reoccurrence and should allow time to include the necessary design change in the next aircraft model.

MILITARY SPECIFICATION FOR HUMAN ENGINEERING

Although designers always have paid some attention to human characteristics when designing machines for their use, human engineering as a trade was boosted by certain military specifications which require military equipment contractors to "human engineer" their products. These specifications require that the work be done in accordance with good human engineering design principles. If the designer will follow the specifications set forth in these documents there is a greater likelihood that maximum man-machine compatibility will be achieved.

It is not necessary that the crewmember be an expert in all the varied military specifications for human engineering design, but he should be aware of their existence and should refer to them. A partial listing is provided below. Special attention should be given to MIL-STD-1472B. This is the most comprehensive of all the military specifications and will provide the user with quick reference to acceptable human engineer design criteria. A detailed listing of military specifications is presented in Appendix B.

SPECIFICATIONS

MIL-STD-1472B - Human Engineering Design Criteria for Military Systems Equipment, and Facilities

MIL-STD-203E - Aircrew Station Controls and Displays for Fixed Wing Aircraft

MIL-STD-250C - Aircrew Station Controls and Displays for Fixed Wing Aircraft

MIL-STD-411D - Aircrew Station Signals (Color Codes)

SD24J Vol. 1 General Specification for design and construction of aircraft weapons systems, rotary wing aircraft.

SD24J Vol. 2 General Specification for design and construction of aircraft weapons systems, rotary wing aircraft.

DISPLAYS

DISPLAY FUNCTION

Displays in man-machine systems link the man to the machine by presenting coded symbolic information concerning a particular aspect of system status. The efficiency of the display in presenting the information will have a direct effect upon the speed and precision with which the operator will be able to perform his required functions.

TYPES OF DISPLAYS

Most displays are visual, some are auditory, and a very few are cutaneous. Auditory and cutaneous displays are used primarily for warning the operator of an emergency situation and to attract his attention to other displays. The following are types of displays most often encountered in aircrew stations:

a. Special flight instruments

b. Meters

c. Numeric displays

d. Event indicators

e. Annunciator lights

f. Warning bells, buzzers, horns

SPECIAL FLIGHT INSTRUMENTS

This type of display includes flight directors, altitude indicators, range-rate meters, horizontal and vertical situation indicators. Due to the complex nature of these types of displays, there are unique problems that warrant special consideration at this time.

a. Spatial Orientation - Specific displays are to provide the operator with information on spatial location. For example, the horizontal situation indicators must

provide timely, accurate and reliable inputs as to where the system has been, where it is now and where it is going. The display should not require the operator to "put it all together" from various inputs, but by the same token we cannot allow instruments to be integrated to the point that they become multi-functional, multi-scaled, multi-pointered monstrosities. Only essential information should be presented by the display. The display should not present so much information that the operator must sort out needed information or it should not present too little information as to cause the operator to have to supply ungiven information.

b. Dimensional Realism - If something moves in the real world then the indicator for that something should move on the instrument panel. If something is stationary in the real world, then it ought to stay still in the display. This principle extends to direction, too. In an altitude display, up is up and down is down. In an altitude or navigation display, clockwise is clockwise and counter-clockwise is counter-clockwise, and in a steering display right is right and left is left.

This principle brings up the "fly to" vs. "fly from" issue which has been argued back and forth for many years. Apparently the reason for "earth-reference" (keeping the artificial horizon bar parallel to the earth's horizon during a roll) was to reduce the pilot's "mental effort"; i.e., you would give the pilot the impression he was actually looking at the horizon. It happens, however, that the "natural" interpretation is to consider the horizon bar as the "figure" or aircraft instead of as the background. The wings and tail of the figure are seen as an extension of the pilot's own body. This natural interpretation has caused reversal errors, in which the pilot may manipulate the controls so that the aircraft rolls in a direction opposite to that intended.

The evidence in favor of realistic representation of dimensions by a moving airplane indicator is not confined to attitude indicators, of course. For a downward looking display, it is better to have a stationary map and a moving airplane than it is to have a stationary airplane and a moving map. Heading control is easier, too, if you have fixed heading reference line and can fly the plane toward the heading. The moving-airplane indicator also helps more in recovering from spins. This was proven in flight tests. Many studies could be cited, but the point is clear: the moving airplane representation generally is superior.

c. Pursuit Displays Versus Compensatory Displays - The coordinated military mission is organized around a concept of closely following a definite flight path, delivering a weapon at this juncture on the path, etc. The pilot is given certain desired positions, attitudes, or directions. These indices of desired performance, or

"commands", may be derived from ground control centers, from airborne computers and from other sources. The important thing is how the commands should be displayed. Should the pilot's display show index of desired performance and the index of actual performance on a standard background scale? This is the "pursuit" display, because the pilot attempts to chase his own plane index into the desired-performance index. Or, should the pilot be given a "compensatory" display, in which the signal is an error signal and his task is to "null" the error?

The pursuit display usually is the best. Display movement should resemble the direction of the error itself rather than the direction taken to correct the error. Probably the main reason for this is the feedback you get from the pursuit situation. Because you can see both the target index and the actual index, you can parcel out the error and you can interpret whether a given error is due to change in the target or due to your own changes. You also can estimate target accelerations. This kind of interpretation is impossible when you are given just an error signal.

d. Standardization - When we say a man has a "set" to respond in a certain way, we mean that he behaves in a prepared, organized way--that he attends to certain aspects of the situation and ignores others, and that he has made some of his procedural decisions in advance. We have already brought out that the pilot establishes spatial reference sets. The important point here is that shifting from one set to another imposes a great strain on the operator. All sorts of errors, momentary blocking, and frustration effects can be noted under conditions where intermittent set changes are made. These negative effects are usually more pronounced under stress. The implication for the instrument designer, of course, is that spatial indicators should be consistent with one another. Related displays should be about the same scale factors. The principle extends to controls as well; uniform direction-of-motion meaning must be maintained for linear and for rotary controls.

e. Wide-Range Perspective - It helps to see where you are going--not just a little bit about where you are, but all the places you might go. The wider the sphere of action possibilities presented, the more likely the aviator is to make the best overall decision. In other words, give the man in the plane a good look around.

This principle is bound to run into practical limits of display scale and size. In compromising between an ideal and a possible presentation, careful attention must be given to the precision limits which actually have to be met. It is often found that though a successful mission needs great accuracy at one or two critical junctures, continuous maintenance of this accuracy is both burdensome and unnecessary. It may

be good business to sacrifice a little accuracy in order to gain a bigger overall picture of the situation.

f. Symbolic Versus Pictorial Displays - It is worth noting some of the relative advantages and disadvantages of symbolic versus pictorial displays to suggest some of the compromises that design engineers have had to make.

Generally, three types of reading functions are served by flight instruments: check reading for assurance of a normal or desired indication, qualitative reading for the meaning of a deviation from a normal or desired indication, and quantitative reading for the exact scale value.

Symbolic instruments (e.g., dials and pointers) can serve all three types of reading functions. However, pictorial displays must be supplemented with symbolic indications for quantitative reading, since the picture available in visual flight is itself deficient in quantitative information.

It may be more economical and efficient to present data in the language and numbers which the pilot customarily uses in these thought processes, rather than in a picture. On the other hand, symbols are substitutions for the real thing, and, as such, depend upon training for their proper use. Pictorial displays might therefore be expected to require less training, be more easily interpreted, and give way to fewer interpretation errors.

METERS

The meter is a common display instrument in most present day crew stations. A modified version can incorporate a feedback loop and is then termed a servometric meter. The basic simplicity and inherent response characteristics of the meter, its compatibility with conventional analog transducers and signal conditioners, and the extensive experience with this type movement are the primary factors in its selection as a general type of display.

Although the servometric meter provided improved accuracy and minimized vibration-induced pointer movement, the mechanism had certain undesirable features. For example, the standard meter inherently moves off scale with loss of signal and thus gives a positive failure indication. With the servometric meter, however, loss of the additional power input (or internal power) leaves the pointer at its last position. Unless the operator has another source of information, he is led to believe that the parameter is unchanged. This problem can be circumvented by the addition of a small

signal light above certain crucial displays. This light illuminates whenever meter input power is interrupted. Servometric displays, when used, should be designed to provide a positive indication for both loss of signal and power.

Meters in crew stations can include single and dual scale vertical meters, single-scale circular meters, dual-scale semi-circular meters, and cross-pointer indicators. Minimization of panel space and crew preference for either vertical or circular meters are the primary factors in the selection of the type of meter to be used. To conserve panel space (and to reduce weight and electrical connections), dual-movement meters can be used, where possible, for the display of related parameters. However, crew comments about the poor readability of the dual-scale, semi-circular meter configuration has resulted in its omission from many designs. For the purpose of standardization, circular meters are being used to display communications and electrical power systems parameters in most crew stations.

NUMERIC DISPLAYS

Numeric displays of both the electro-mechanical rotating drum and the electronic EL-segment type can be used for certain applications in which precise quantitative data are required and trend information is not of primary importance. Among the applications are the display of mission and event times, propellant quantities, and computer parameters.

EVENT INDICATORS

Electro-mechanical event indicators, more popularly known as "flags", are used to show the status of components or system elements. Generally, flags are used as indicators of discrete normal events such as valve opening or closing, but, in a few applications, they are used as malfunction indicators.

In some cases, flags can be used in preference to annunciator lights for general status indications. Their use conserves power, facilitates dark-adapted operations and helps to eliminate an objectionable "Christmas tree" effect. Unfortunately, the inconspicuousness of flags could also easily allow an abnormal change in the state of the monitored element to go undetected by the operator. Therefore, flags are generally used as status indicators and not as caution or warning indicators.

ANNUNCIATOR LIGHTS

Annunciator lights are used when a discrete, attention-getting display is required. On standard crew stations, annunciator lights are generally used to provide subsystem or component malfunction information in association with the caution and warning system, but they are occasionally used as event indicators. The amber caution and red warning lights are generally grouped and centrally located for easy visibility by all crewmembers. A master alarm light and an auditory alarm can be operated in conjunction with these lights. These alarms will activate simultaneously with the pertinent control and warning light whenever an out-of-tolerance condition exists among the monitored parameters. To distinguish between different failures, two different auditory signals can be used. For example, one failure can be a dual-frequency (750 and 2000 hertz) alternating tone; another failure a single-frequency (3000 hertz) tone. Some crew stations additionally use component caution lights, subordinate to the control and warning lights that show which of several subsystem elements gated into a single control and warning light had malfunctioned. Flags may also be used in a similar function.

To avoid the distraction of constantly illuminated annunciators, they should have extinguishment controls. Problems are of inadvertent nuisance triggering caution and warning annunciators should be eliminated.

A good caution and warning design would have the following capabilities: an acknowledge mode, dedicated resets/inhibits for each caution and warning channel, a memory or latching system for identifying the source of short-term abnormalities, a variable time delay for screening transients in individual caution and warning channels, and the capability to alter the alarm limits easily.

PRINCIPLES OF DISPLAY DESIGN

Only general display principles useful in your crew station evaluation will be presented. For more detailed and extensive lists consult any one of many human engineering handbook guides. This list does not represent inviolate rules, but should be of some assistance in display evaluation. The following should be true of most displays:

1. The most important displays should occupy the most prominent area at eye level ± 15 degrees.

2. Displays watched continuously should be in the center of the control panel; those watched only during certain operations should be grouped together farther from the center.

3. Display indicators (pointers, markers) should be designed to foster eye scan that goes horizontally left to right or vertically bottom to top.

4. Warning and emergency displays should be as near as possible to the central line of sight.

5. Warning and emergency displays should provide unambiguous consistent information with immediate obvious meaning.

6. Displays should be interpretable under various lighting conditions, e.g., strong day light or night conditions should not interfere with information presentation.

7. Displays should present indications which are easily verbalized or visualized.

8. Displays should present information as accurately as necessary, but no more accurately than required.

9. Changing or changed indication should be easy to detect.

10. Displays should provide information in an immediately useable form without requiring calculation or translation into other units.

11. Displays should be free from error-producing features such as cause orientation-reversal on the artificial horizon and misreading of multi-revolution or multi-pointer dials.

12. Displays should foster the recognition of errors, so that they do not persist.

13. Displays should inform the operator which control to use to change its information.

14. Displays should inform the operator in which direction to operate the control.

15. Displays should inform the operator when, how much, and for how long to move the control.

TYPES OF DISPLAY ERRORS

To determine typical errors made in the use of displays a study was conducted that compiled pilot errors in responding to displays. The greatest number of errors in this survey involved the interpretation of display signals. The most frequent error was misinterpreting the direction of indicator movements. The third most frequent type of error in this survey was inadequate direction characteristics in the displays when

the pilots failed to respond to warning lights or sounds. Finally, the fourth most frequent error was misinterpretation as a result of poor legibility of numbers and letters.

Examples of these type of errors are presented below:

a. Errors in interpreting multi-revolution instruments:

(1) Errors involving an instrument which has more than one pointer, e.g., misreading the altimeter by 1,000 feet, the clock by one hour, etc.

(2) Errors involving an instrument which has more than one pointer, e.g., misreading the altimeter by 1,000 feet, the clock by one hour, etc.

b. Reversal errors, e.g., reversals in interpreting the direction of bank shown by a flight indicator, reversals in interpreting direction from compasses, etc.

c. Legibility errors:

(1) Instrument markings difficult or impossible to read because of improper lighting, dirt, grease, worn markings, vibration, or obstructions.

(2) Parallax: Difficulty in reading an instrument because of the angle at which it is viewed.

d. Substitution errors:

(1) Mistaking one instrument for another, e.g., confusing manifold-pressure gauge with tachometer, clock with air-speed meter, etc.

(2) Confusing which engine is referred to by an instrument.

(3) Difficulty in locating an instrument because of unfamiliar arrangement of instruments.

e. Using an instrument that is inoperative, i.e., reading an instrument which is not working or is working incorrectly.

f. Scale interpretation errors, i.e., errors in interpolating between scale markers or in interpreting a numbered graduation correctly.

g. Errors due to illusions: Faulty interpretation of the position of an aircraft because body sensations do not agree with what the instruments show.

h. Signal interpretation errors: Failure to notice warning light in the aircraft, or confusing one warning light with another.

The principles of display design presented earlier and the above most frequently encountered display errors coupled with the test procedures in the test procedures section should aid the TPS student in evaluating most crew stations.

CONTROLS

PURPOSE OF CONTROLS

The various control devices are the means by which the operator can manipulate the system to a desired state. Only through control manipulation can the operator provide effective inputs into the man-machine loop. Therefore, the more effectively the controls are designed to improve operator responses the more efficient the total system. The purpose of the controls are to link the man to the machine by providing necessary devices to allow the operator to perform required functions.

TYPES OF CONTROLS AND THEIR USES

One author has categorized controls as follows: (1) Activation controls, like dichotomous displays, involve only two possible states, such as on or off. (2) Discrete setting controls, on the other hand, offer any one of several positional settings and are analogous to qualitative displays. (3) Continuous controls and (4) quantiative setting controls offer a wide range of control positions anywhere on a quantitative continum. The difference between the two is that a continuous control, as the name implies, is operated continuously, whereas the quantiatative setting control, although it offers a continuous range of positions, is generally manipulated only discretely into one position or another (such as a thermostat control). Both of these types of controls are similar to quantitative dynamic displays in function.

The control devices used in most crew stations include:

a. Toggle switches,

b. Pushbutton switches,

c. Rotary switches,

d. Continuously variable controls,

e. Circuit breakers.

TOGGLE SWITCHES

Toggle switches are a frequently used control device. Chief factors favoring their selection are that toggle switches generally require less panel space, give a positive status indication (except for momentary switches) and are easy to actuate under a variety of flight conditions. Two- and three-position switches with various

combinations of maintaining and momentary positions are used to actuate or select operating conditions or components. Maintaining switches are used for most applications. An inherent advantage of the maintaining-type switch is a visual indication of switch position and, therefore, of system and vehicle configuration. The momentary-type switch, in which the handle is spring-loaded to return to another position, does not give such inherent status indication. For most functions initiated with momentary switches, such as opening a latching valve, some type of adjacent status indicator is necessary. This requirement for a status indicator to be used with most momentary toggle switches means that an additional component and more panel space is required than if a maintaining type toggle switch is used. Status indicators provided with momentary switches, however, have the added advantage of providing the end-item status of the equipment being controlled, whereas a maintaining switch, in itself, gives no such information.

The operator should be aware of the problem with the three position switches in order to avoid mispositioning or misinterpreting the switches. The possibility of increasing the deflection for three-position switches should be considered in crew station design because many of these switches have been mistakenly mispositioned or monitored (or both) by many operators.

PUSHBUTTON SWITCHES

Pushbutton switches are used for applications requiring the rapid initiation of a function, for high-frequency-of-use situations, and for applications requiring a combined control/signal device. Pushbutton switches are most widely used for applications requiring the rapid initiation of a function. In some cases pushbutton switches can be used as manual backup controls to initiate various sequential events. Pushbutton switches, in a keyboard format, can be used to enter data into system computers. Master alarm pushbutton/signal lights can serve to indicate caution and warning conditions and to reset the alarm circuitry.

ROTARY SWITCHES

Rotary switches are used when four or more detent positions are required for discrete functions, or in applications that require many poles or high-current capacities. In the latter applications, the design of a rotary switch is generally more suitable than the design of a toggle switch.

Rotary switches are highly advantageous in accomplishing numerous switching functions, but this capability in turn increases the criticiality of a failure. A

mechanically jammed rotary switch, for example, could inhibit all the switching functions normally performed by the control. Therefore, some rotary switches are positioned in the most critical detent positions before a given critical event; and, if possible, mission critical rotary switches can be replaced with (and by an additional number of) toggle switches

CONTINUOUSLY VARIABLE CONTROLS

Continuously variable controls, such as potentiometers, rheostats, and variable transformers, are used for functions requiring precise control and adjustment of system or equipment parameters. Some of these functions included the control of lighting intensities, audio volume, and dantenna positioning. Continuously variable controls are equipped with thumbwheel and rotary-switch type knobs. Thumbwheels are used predominantly for audio controls and knobs for lighting and antenna controls. The periphery of thumbwheels is marked with intergers from one to nine for indexing the control.

CIRCUIT BREAKERS

Circuit breakers are used primarily to protect electrical circuits. Sometimes, however, circuit breakers are used as control devices; this application occurs mostly in crew stations, where weight is very critical. In all these instances, though, an attempt is made to design the systems so that switching actions are limited in number and conducted under a no-load condition. Circuit breakers can be procedurally used to disable critical circuits during periods when they are not required.

Circuit breakers are particularly susceptible to inadvertent actuation or damage under certain conditions. This susceptibility is especially prevalent when the amount of crew activity is associated with limited space. Therefore, special precautions should be taken to protect the circuit breakers by recessing the panels or by providing barrier guards or by both methods. Circuit breakers should not be used as switches.

PRINCIPLES OF CONTROL DESIGN

The control design engineer must be acutely aware of the characteristics of man as a "responder". So far as the aircraft control loop is concerned, the amazing flexibility and versatility of the eye-hand combination is most important. Designers should attempt to develop switches, knobs, levers, cranks, wheels, and pushbuttons that will capitalize on the characteristics of this combination.

The human operator is capable of remarkably fine control--if the control system he works with has been properly gauged to his characteristics. As a result of systematic studies on human control functions and requirements, man is serving as a more efficient control link all the time. In this section, some of the broader issues involved in the design and arrangement of controls will be presented.

Population Stereotypes - We all acquire certain "expected relationships" that we expect to hold when we turn a crank or push a lever. Some of these were mentioned in connection with cockpit displays. The designer must take advantage of them. Generally speaking, control movements should be in the same plane and in the same direction as the pointer movement. Flipping a switch up means on; flipping it down means off. Lever movements to the right or forward mean forward, plus or increase; left and backward movements mean backward, minus, decrease, or reverse. Clockwise rotation of a crank facing the operator naturally signifies that the indicator will move to the right. And with the "fly-to" vs. "fly-from" issue the untrained operator is naturally more comfortable with the aircraft reference (fly-from) indication

The following is a list of additional general population stereotype reactions that are applicable to crew station design.

a. For control of vehicles in which the operator is riding, the operator expects a control motion to the right or clockwise to result in a similar motion of his vehicle and vice versa.

b. Sky-earth impressions carry over into colors and shadings; light shades and bluish colors are related to the sky or up, whereas dark shades and greenish or brownish colors are related to the ground or down.

c. Things which are further away are expected to look smaller.

d. Very loud sounds or sounds repeated in rapid succession, and visual displays which move rapidly or are very bright, imply urgency and excitement.

e. Very large objects or dark objects imply "heaviness". Small objects or light-colored ones appear light in weight. Large, heavy objects are expected to be "at the bottom". Small light objects are expected to be "at the top".

CONTROL CODING

The reason for coding controls is to make them easy to identify. Proper identification is important not only for preventing activation of the wrong control but for lessening

negative transfer when the operator has to change from one control arrangement to another. The primary coding methods are by shape, size, location, and color.

a. Shape - Under blackout or other visual conditions it may be necessary to identify levers and knobs by shape. Discriminability studies have revealed which shapes are least likely to be confused with each other, and certain standard shapes have been adopted for military use. It makes a difference, however, as to the function of the control. Thus, for a detent positioning control you need a control with a pointed end, while for a multiple-rotation control you want a knob that can be twirled easily. The Navy has standard knobs for some aircraft controls which have symbolic significance. Thus, the landing gear knob is shaped like a wheel, the flap control like a flap cross section, etc.

b. Size - Identifying controls by size alone is rather limited by the small number of sizes that can be used; with more than three categories, confusion is likely if absolute size judgements are made. About the only case where size coding is clearly indicated is in a control arrangement where one large know is used for gross settings and a small knob is used for finer adjustments.

c. Location - Having the proper space for controls enables the operator to set up habit patterns of reaching and manipulation. If controls must be located in the dark by position only, they should be separated by at least five inches if located in the center of the panel. Separation should be greater if the controls are off to one side.

Perhaps the most important principles of location coding, or arrangement of controls, are the frequency-of-use principle and the sequence-of-use principle. In the former, it is recommended that the controls used most frequently be placed in preferred locations and in relatively close proximity to each other. When considering sequence of use, on the other hand, it is recommended that the controls be placed in a proximal or spatial sequence that corresponds to the order in which they are to be used.

Other principles of control location include functional arrangements in which controls with related functions are placed together; arrangements according to importance, in which controls with the most important functions are given prime locations; and optimal location arrangements, in which controls are arranged in such a manner that optimal manipulation of the total ensemble is achieved. It is apparent that while some of these location principles are complementary to each other, some are also contradictory. Consequently, in the design of controls and control panels, each of the principles should be evaluated in view of the total control functions. After trade-offs

have been made and a decision has been reached, any effort to standardize the agreed-upon control arrangement inherently involves location coding.

d. Color - Color is b est as a supplementary coding technique, because it changes and is eventually lost as a cue as illumination is reduced. Standard color codes have been specified for Navy aircraft and ground equipment. Red refers to fire extinguisher handle, and landing gear control handle. Amber is the master caution color. Orange-yellow signifies emergency exists and exit releases. Control wheels and control stick grips are black. General standards for color coding are given in MIL-STD-1472B.

CONTROL FORCES

The operator has to apply some force in order to move a control. The question is, how much force should he be required to exert? With booster control systems, the aircraft designer has plenty of leeway in setting up control loads for the operator. The situation is, as usual, full of variables, but the fundamental rules are clear enough. For example, one may compensate for this differential discriminability of forces by adjusting controls so that (1) when they are operating in regions of poor sensitivity, relatively large increments of force are required to accomplish a given movement, and (2) when operating in regions of better discrimination correspondingly smaller increments of force are required for that same movement.

TYPES OF CONTROL ERRORS

Many of the problems associated with controls are similar to those associated with displays. Such problems involve control display compatibility, controls which cannot be easily manipulated because they are out of reach or are not organized in a meaningful fashion, and overloading of manipulations by the hands as a result of too many manual controls.

A survey of control errors most often encountered by pilots included:

a. Confusion of Controls.

This most often results from improper arrangement of controls.

b. Manipulation of a control in the wrong direction.

This most often results from control-display incompatibility in relation to pilots expectations.

c. Forgetting to use a particular control.

This usually results from poor arrangement of controls.

d. Accidently moving the wrong control.

This usually results from poor arrangement of controls.

e. Inability to reach a control.

This usually results from the improper use of anthropometric criteria.

Just as the problems associated with controls are similar to problems associated with displays, so are the solutions similar. The principles of compatibility, standardization, selection, and arrangement, are involved in both fields of engineering endeavor.

CONTROL-DISPLAY INTERRELATIONSHIPS

CONTROL-DISPLAY DESIGN TRENDS

Designing for control-display interrelationships involves many of the considerations that are involved in the design of both controls and displays. For example, the principle of control differentiation is closely related to the detectability and identification principles of display information and efforts must be made to make controls as easily discriminable and accessible as possible. Also, controls take into account the same factors that contribute to a "naturalness" of response in interpretation and decision making considerations in the design of displays. Such factors include standardization, conformation to population, stereotypes, and control-display compatibility, also, just as the more complex quantitative displays involved the most extensive design considerations, so the more complex continuous controls require the greatest degree of design sophistication.

It should be pointed out that it is very difficult to distinguish between the principles involved in the design of these control-display interrelationships and separate design of controls and displays, since the input and output functions of the human being cannot easily be separated. The form of information input has a direct influence on how well the output response can be made. Ideally all controls and displays should always be designed to be compatible to each other. Employing this "system" concept, a more smoothly functioning arrangement of components can be designed. The "system" concept in design is evident from examining crew stations over the years. It has evolved to the point that current design trends for manned aircraft give the

operator certain monitoring and decision-making functions to perform and relegate routine, repetitive, and complex computational tasks to machine components. This is apparent in such aircraft as the S-3A, A-7E, and F-14.

CONTROL-DISPLAY DESIGN PRINCIPLES

Some of the control-display interrelationships that are important for crew station evaluations are summarized below as design principles. Although no one of them can be followed blindly, together they summarize worthwhile considerations.

a. The Functional Principle - The prescription is: Group together on the panel the displays and controls that have the same function. To the aviator, the first illustration that comes to mind would be to have the engine displays and controls separate from flight instruments.

b. The Importance Principle - The most critical displays and controls are placed in the easiest to see and easiest to reach places. The inverse of this principle is also helpful, because there are generally some definitely subsidiary display and control devices; these can be parcelled out around the less visible locations, right at the beginning.

c. The Standardization Principle - From one airplane model to another, the fundamental display-control arrangement should be similar. Thus, landing gear and flap controls should be similarly placed and coded, regardless of airplane.

d. The Load Distribution Principle - No one sense or part of the body should be overloaded with sensing or action tasks that can be accomplished by other parts. For instance, one may use audition instead of overloading vision. The right hand shouldn't do all the work.

e. The Optimal Position Principle - By the nature of the task, some displays and control should have an optimum location. For maximum arm pull strength, you need arm and shoulder involvement at a point straight out from the shoulder. Displays are easiest to see at eye height directly in front of the operator. Controls to be used "blind" should be right in front and quite high on the panel.

f. The Frequency-of-Use Principle - Put frequently used elements in preferred locations. As an illustration, during a straight climb-out it was found that pilots spend nearly three-fourths of their looking-time on just three instruments: air speed, directional gyro, and gyro horizon.

g. <u>The Sequence-of-Use Principle</u> - Take advantage of the sequence of actions in laying out a system. If control Y is always to be activated right after control X, put Y right next to X, etc. It also is important in laying out optimal check-off procedures.

ENVIRONMENTAL EFFECTS ON HUMAN PERFORMANCE

No man-machine system operates in a vacuum, and the surrounding environment has a very real effect on the adequacy of human task performance. Some of the important variables in the job environment are the illumination the atmospheric conditions and noise effects.

GENERAL ILLUMINATION REQUIREMENTS

The level of illumination required for adequate human performance is task specific. There is no best amount of light for all tasks. Therefore, the problem is to provide as much light as is needed to adequately and comfortably accomplish a specific task. While generally it is more acceptable to have more rather than less illumination that is necessary, high levels of illumination can reduce the information transfer characteristics of visual displays. This results primarily from a reduction in the display's visibility characteristics due to excessively high illumination. Under conditions of high illumination, glare on the faces of visual display can make it difficult to read displays. Indirect lighting is a common solution to the glare problem, although localized illumination (illumination immediately over the specific work area) should be somewhat brighter than the ambient illumination. Also, as was mentioned in discussion display contrast characteristics, the greater degree of contrast between the displayed information and its immediate background, the less illumination necessary for adequate detection of such information.

NIGHT ILLUMINATION REQUIREMENTS

In general, crew station illumination of displays and controls should provide for the optimum utilization of the crew's capabilities. However, two conflicting visual tasks are required of most crewmembers in an aerospace vehicle during hours of darkness: (a) reading the cockpit control displays and activating the various controls and (b) scanning outside the vehicle for other lighted objects, such as aircraft or landmarks. Within limits, the ability to read the displays and markings inside a crew station increases with increasing brightness, contrast, visual acuity, time, and size of the markings, whereas the ability to see outside a vehicle is greatest when the crewmember is in a state of dark adaptation, which is accomplished when the eye is

subjected to a state of complete darkness for a period of approximately one-half hour. Even the low level of light needed to interpret the crew station controls has a detrimental effect on dark adaptation.

RED VS. WHITE LIGHT

The use of white or red light for the primary lighting system in a crew station is very controversial. Without getting into this subject in its entire depth, the following rules should apply as requirements for choosing a lighting system:

a. If the primary task of the crewmember is to view outside the vehicle at night and he must have the best dark adaptation while performing the task of monitoring inside the crew station, red light should be chosen.

b. If the primary task is inside the vehicle monitoring the instruments and controls and dark adaptation for scanning outside the cockpit can be compromised without danger, then white light as a primary system should be used.

The above red or white guidelines cannot always be followed since other factors affect the decision. For example, the crew stations presently being utilized and designed are, in many cases, being equipped with "large" TV displays, scope reading radars, photo-projectors, etc. These displays emit energy at various wave lengths (colors) but, for specific purposes, the range is from one end of the visible spectrum to the other. These presentations, are not compatible with a crew station that is dark adapted (or color adapted) for two reasons: (a) they tend to destroy dark adaptation, and (b) they subject a dark-adapted (or color adapted) eye to unbearable eye strain and fatigue.

In crew stations where the operator does not have an outside visual task, this problem can be solved by using "white" indirect flood-lighting. Thus, since white "unfiltered" light contains all colors, any color that is required can be used in this crew station.

In crew stations where the operator is required to accomplish a visual task outside the crew station during hours of darkness while viewing displays and operating controls inside the cockpit, the problem is more difficult. The best choice is "unfiltered" white light. Thus, the "purple" TV, the "orange" radar, and the "yellow" data viewer could be viewed satisfactorily at a very low level of unfiltered white light and yet allow tasks outside the cockpit to be accomplished with minimum destruction of dark adaptation. Any filtering of the white light under this condition has the same effect as red light.

CREW STATION ILLUMINATION SUBSYSTEMS DESIGN PRINCIPLES

Crew Station lighting systems can be broken into five subsystems, each of which can be designed separately, but all must be compatible with each other.

a. Instrument and Display Illumination

b. Control Panel Illumination

c. Warning Indicator Illumination

d. Floodlights

e. Thunderstorm Floodlights

INSTRUMENT AND DISPLAY ILLUMINATION

The most important factor in designing instrument and display illumination is the control of light distribution. A crewmember must have all displays illuminated with the same intensity. The dimming control for instrument and display illumination must control the level of light intensity from off to full bright, and all of the systems must have an even, balanced intensity over the entire dimming curves, so that the crewmember can obtain the maximum amount of dark adaptation for viewing outside the vehicle.

CONTROL PANEL ILLUMINATION

As is the case of instrument and display illumination, panel illumination must be even and balanced for the same reasons. It is absolutely necessary that all indicia be visible and evenly illuminated. Also, all switch handles, control knobs, counters, etc., must be illuminated. If the control must be viewed during daylight hours, it must be equally visible during darkness with no windscreen or canopy reflection.

WARNING INDICATORS

These presentations take on many forms and shapes; but, in the majority of cases, they are in essence "illuminated legend plates". That is, the legend plate is black until actuated, and then it is illuminated and can be read.

First the "do's: and "don'ts": Don't attempt to outshine the sunlight entering a glass canopy cockpit with any indicator that utilizes a lamp to attract the attention of the crew member. No lamp made, especially the small miniature types usually used for this purpose, can outshine the sun; that is, the lamp cannot emit more light out

through the legend plate, than the sun can emit into it. Therefore, the crewmember will not be aware that the indicator has been illuminated. Conversely, as one pilot put it, "Bad news should be broken to a crewmember gently, not harshly". He means by this that a crewmember should not be blinded when a warning indicator is energized during darkness. Therefore, adequate dimming should be inserted in the lamp circuit to compensate for the ambient light level. Another factor that must be considered is providing an adequate means to eliminate, or reduce to an acceptable level, the light emitted by a warning indicator after the crew member is adequately advised. It should not be necessary for a crew member to have to put tape over the indicator, remove the lamps, smash the lamps, etc. to get rid of the harsh, glaring, uncomfortable light that shines in his eyes while he is trying to control a disable aerospace vehicle. Red-illuminated indicators are also used as warning indicators that denote "Safety of Flight". These are usually classed as "Fire", "Low Fuel", etc. Amber-colored "CAUTION" indicators are utilized to bring the crew member's attention to an unsatisfactory condition that would affect the mission, such as "Radar Out", "Autopilot Out", etc. The intensity of these indicators is the same as the warning indicators. These indicators are also very distracting; therefore, the dimming characteristic, or the ability to turn them off after they have served their purpose, must be provided.

Advisory indicators are illuminated with green light and are used to advise the crew member of certain pertinent information, such as "Heater On", "Defrost Off", "Angle of Attack", etc. The dimming rules apply here, but the intensity should not be as bright as a warning or caution indicator. It should be the same as an illuminated instrument, because they are used to display information and not be attract attention to an unsatisfactory condition.

FLOODLIGHTS

A low level floodlight in a crew member's station in an aerospace vehicle is required to give position to all of the indicia or the instrument displays and control panels, so that the crew member will not suffer from hallucinations. These floodlights should be dimable, so that the crew member can adjust them as a function of the crew station ambient light level.

THUNDERSTORM FLOODLIGHTS

Sufficient white floodlights should be available to illuminate an aerospace crew station

in the event flight through a thunderstorm is required, because lightning can destroy dark adaptation.

SUMMARY OF GOOD CREW STATION LIGHTING DESIGN

1. Suitable brightness for the task.

2. Uniform lighting on the task.

3. Suitable brightness contrast between task and background.

4. Lack of glare from either the light source or the work surface.

5. Suitable quality and color of illuminates and surfaces.

COMMON MISCONCEPTIONS REGARDING LIGHTING REQUIREMENTS

a. That you can create unequivocal light level standards.

b. The more intensity provided, the better people can see.

c. That optimum visibility is the only real consideration specifying illumination.

d. That illumination can be considered independently after systems hardware design is completed.

COMMON ILLUMINATION ERRORS

a. Too much, as well as too little, light for the task.

b. Poorly distributed light.

c. Exposing the eye to the light source.

d. Improper utilization of secondary surfaces to absorb or reflect light.

e. Lack of flexibility for operator control of workplace lighting; or too much individual control.

f. Lack of consideration for the total functional lighting requirement e.g., maintenance, as well as operational tasks.

g. Lighting conceived without regard for the interference people and equipment introduced later.

h. Light directed "at people", rather than on the task they perform.

i. Illumination system design which cannot be maintained.

j. Lack of color and quality compatibility between illumination and workplace surface and materials.

In general these errors can be summarized as the over-emphasis on the quantity of light, poor distribution, glare and incompatibility with the general user requirements.

VENTILATION

Ventilation is a complex variable involving temperature, humidity, and air movement. When the human engages in physical activity, the activity produces heat within the body that must be dissipated through pores of the skin. The effectiveness with which this process of perspiration can dissipate the heat buildup in the body is primarily dependent upon the three aspects of ventilation just mentioned. As a result, the interaction of temperature, humidity, and air circulation is an important factor determining the productivity level, accident rate, and morale of the workers.

Effective temperature scales are useful in determining optimal atmospheric conditions for various tasks. Usually temperature around 70 degrees Fahrenheit is considered most comfortable for jobs requiring moderate exertion. For heavy exertion, optimal temperatures are lower and for light exertion temperatures as high as 80 degrees may be acceptable.

NOISE

There have been conflicting opinions about the effects of noise upon work performance. Some maintain that noise is detrimental to task performance, especially in repetitive tasks, and others maintain that noise can in some situations enhance performance. Clearly, more research is needed on this matter. However, there is a considerable amount of evidence indicating that prolonged noise is detrimental to the work situation. Certainly, loud ambient noise levels interfere with speech communication, and there is growing evidence that prolonged exposure to such conditions may result in physiological damage in the form of a hearing loss. Also, due to an apparent increase in muscular tension and a consequential increase in expenditure of energy it appears that workers in a noisy background become more easily fatigued, nervous, and irritable than those in a quiet background. Research suggests that noises of high

intensity and/or frequency, intermittent noises, and reverberating noises are the most annoying.

Thus, while noise may have little immediate effect on performance, it does appear that noise has definite effects for prolonged tasks. There are, of course, many other environmental factors that can affect performance, such as vibration. However, consideration of all the varieties of environmental variables influencing man's behavior in a system is beyond the scope of this crew station evaluation guide.

ANTHROPOMETRIC CONSIDERATIONS IN CREW STATION EVALUATION

ANTHROPOMETRIC REQUIREMENTS IN CREW STATION DESIGN

Body sizes vary considerably so the design engineer must design for this great range in body measurement especially when designing for visibility and functional accommodation. Prior to 1970 detail airplane specifications required that crewstations accommodate 5th through 95th percentile sized aviators. Since 1970 the 3rd through 98th percentile must be accommodated in all crew stations.

It is generally assumed that if one's body measurements such as height and weight are 50th percentile (average) that all his dimensions will be 50th percentile. This unfortunately, is not true. Uniformity of body dimensions is very rare, e.g., it is doubtful that if a persons sitting eye height is 70th percentile that his functional reach will also be 70th percentile. It is therefore important to realize that as a test pilot doing crew stations evaluation that one should not assume that because your sitting height in 70th percentile all other anthropometric values will be 70th percentile. Be sure to know your exact measurements and apply these in your crew station evaluation.

Physiological Training Units are equipped with anthropometric measuring devices where you can be measured and have your measurements translated into percentile values. The most important dimensions relative to aircrew station design are:

a. Total Sitting Height

b. Sitting Eye Height

c. Sitting Shoulder Height

d. Functional Reach (grasp between thumb and forefinger)

e. Fingertip reach ("pushbutton" reach with extended forefinger)

f. Buttock-to-knee length (sitting)

Only by knowing your own anthropometric percentile value can you make relative judgements as to the overall anthropometric accommodation of a particular crew station, e.g., if you know your functional reach is 35th percentile and that you can't reach a particular control when fully restrained, obviously you know that anyone with a functional reach less than 35th percentile cannot reach the control.

DESIGN EYE POSITION AND CREW STATION ANTHROPOMETRIC EVALUATIONS

It is imperative that the design eye position (DEP) be the source of measurements for anthropometric evaluations. In general, the DEP is the point in space where the pilots eyes should be positioned in order to see all displays plus adequate exterior vision. To further clarify the DEP, other definitions are presented below:

a. Seat Reference Point - is a center line intersection of the seat back tangent line and seat surface.

b. Neutral Seat Reference Point (NSRP) - is the location of the seat reference point when the seat is adjusted to the mid-point of vertical adjustment, e.g. with 5 inches of vertical seat travel available, the seat would be adjusted to 2.5 inches above the lower limit.

The DEP is then defined as the point in space located at the sitting eye height dimension of the 50th percentile aviator (31.5 inches) measured vertically above the neutral seat reference point and 13 inches measured horizontally forward of the seat back tangent line.

All anthropometric evaluations must originate at the DEP. Whatever the size of the individual evaluating items such as control reach, display visibility or cockpit space accommodation, the seat must be adjusted to place they eye at the DEP. The necessity of adjusting the eyes to the DEP when making anthropometric evaluations is more critical now with the increasing emphasis on heads-up displays and other optical devices which require line-of-sight criterion.

As with all human engineering evaluations, anthropometry must be evaluated under all types of conditions. For example, if you were evaluating a "worst case" condition

reaching for a critical control such as the emergency stores jettison it should be done when fully restrained (shoulder harness locked) and when under a high-g condition such as a catapult launch. If the condition can be reached under these conditions it is probable it can be reached under more normal conditions.

TEST PROCEDURES FOR HUMAN FACTORS CREW STATION EVALUATION

GENERAL PROCEDURES

The casual observer who steps into the crew station of a modern day weapon system is confronted with a maze of instruments and controls. Closer study of the entire operation of flying an aircraft further impresses the observer of the complexities involved in the task. One way of evaluating a complex weapon system is to divide the crew station into several general work areas and evaluate each area separately. For example:

Area 1 -- Control column, rudder and brake pedals

Area 2 -- Control Pedestal (upper half)

Area 3 -- Control pedestal (lower half)

Area 4 -- Main instrument panel (lower portion)

Area 5 -- Main instrument panel (upper portion)

Area 6 -- Pilot's upper instrument and switch panels

Area 7 -- Side control panels

It is not really necessary to describe in any greater detail what these areas encompass, for we are concerned here only with developing a systematic approach in order to insure that the entire crew station will be adequately evaluated. In whatever manner the crew station is divided is purely arbitrary and all that is of consideration is that no area is neglected.

Once a particular approach has been adopted, it then becomes necessary to apply the design principles for displays and controls discussed in Part I. That is, you will evaluate all the components within the crew station on how well they conform to good human engineering design principles. For example, you will determine if the most

critical displays are located with the central line of sight, if the controls are in accordance with expected movements or if the warning and emergency indicators are the correct size, color, and location within the crew station, and if crew station procedures are within a standardized framework.

To facilitate the evaluation it may be helpful to use a form that allows you to keep track of all the controls and displays you have evaluated under all the possible conditions of day, night, harness locked and unlocked and emergency conditions. Some record keeping device should be used to insure all components have been checked under all conditions.

EMERGENCY EGRESS

Egress clearances in ejection seat crew stations are often jeopardized when modifications such as cameras, control boxes, or other equipment is added to canopy rails, glare shields, etc. In human engineering evaluation special care should be taken that the escape envelope has not been violated by new hardware design or hardware modifications.

COMMON ANTHROPOMETRIC DEFICIENCIES

Items of anthropometric deficiency include insufficient sitting height, inability to reach rudder pedals, foot controls, inability to fit through emergency egress openings, etc.

The crew station evaluation should reflect as near a possible actual flight condition; therefore, it is necessary that parts of the evaluation be done in complete flight gear. Preliminary examination, of course, does not require full flight gear but for evaluating functional reach, setting height, control-display dynamics, and emergency procedures, full flight gear, should be used to increase validity of the evaluation.

OPERATOR DESIGN EYE POSITION

The crew station evaluation must be done in reference to the Design Eye Position (DEP) as explained in part I. It is, therefore, necessary to set the seat so that your sitting height combined with the seat vertical travel will position you at the DEP. For example, if the seat has 5 inches of travel then the neutral seat reference point will be found 2 1/2 inches up from the lowest seat travel. Knowing the DEP is set for the average aviator (50th percentile) which has a 31.5 inch setting height and you, for example, have a 30.5 sitting height that you must move the seat an additional inch upward or a total of 3 1/2 inches in order to be at the DEP. This procedure should be

accomplished before beginning the evaluation of controls and displays.

SUMMARY OF GENERAL PROCEDURES

1. Develop a systematic approach to the crew station evaluation insuring that all components are evaluated under all conditions.

2. Develop a record keeping mechanism to maintain an accurate account of all work done.

3. Wear complete flight gear for critical evaluations.

4. Determine Design Eye Position as outlined at Part I.

The following subsections present check lists and procedure guides to aid in the crew station evaluation.

TEST PROCEDURES FOR DISPLAY EVALUATION

The displays to be evaluated include:

a. Special flight instruments

b. Meters

c. Numeric display

d. Event indicators

e. Annunciator lights

f. Warning bells, buzzers, horns

GENERAL GUIDELINES

All displays should be evaluated for the following: visibility, legibility, interpretability, arrangement, consistency of reference, useful accuracy, fail-safe provisions, reliability and consistency in each flight mode or mission. In addition, warning and emergency indicators should be evaluated carefully for size, color, and location in cockpit; adequacy of information coding (is the information displayed immediately interpretable without ambiguity, and with an indication of the action to take?); fail-safe provisions, emergency coding (e.g., do the same colors, shapes, or sizes always mean the same degree of emergency?).

To aid you in your evaluation a check list of the most frequently encountered display errors and examples are presented. In addition, display design principles have been arranged into a check list form. All of which are only aids and, in the final analysis, you must decide if the display operating under all conditions works adequately to provide you with sufficient information to do his task. If it does not, then a human engineering error exists.

CHECKLIST OF THE MOST FREQUENTLY ENCOUNTERED DISPLAY ERRORS

a. Is the multi-revolution display easy to interpret and does not lead to confusion of meaning?

b. Is the display indicator clear in its direction of movement?

c. Is the display easy to detect under warning or alert conditions?

d. Is the legibility of numbers and letters sufficient so as not to cause misinterpretation?

e. Errors in interpreting multi revolution instrument.

(1) Errors involving an instrument which has more than one pointer, e.g., misreading the altimeter by 1,000 feet, the clock by one hour, etc.

(2) Errors involving an instrument which has a pointer and a rotating dial viewed through a "window" e.g., misreading the tachometer by 1000 rpm, the airspeed meter by 100 mph.

f. Reversal errors, e.g., reversals in interpreting the direction of bank shown by a flight indicator, reversals in interpreting direction from compasses, etc.

g. Legibility errors:

(1) Instrument markings difficult or impossible to read because of improper lighting, dirt, grease, worn markings, vibration, or obstructions.

(2) Parallax: Difficulty in reading an instrument because of the angle at which it is viewed.

h. Substitution errors:

(1) Mistaking one instrument for another, e.g., confusing manifold

pressure gauge with tachometer, clock with air-speed meter, etc.

(2) Confusing which engine is referred to by an instrument.

(3) Difficulty in locating an instrument because of unfamiliar arrangement of instruments.

i. Using an instrument that is inoperative, i.e., reading an instrument which is not working or is working incorrectly.

j. Scale interpretation errors, i.e., errors in interpolating between scales markers or in interpreting a numbered graduation correctly.

k. Errors due to illusions: Faulty interpretation of the position of an aircraft because body sensations do not agree with what the instruments show.

l. Signal interpretation errors: Failure to notice warning light in the aircraft, or confusing one warning light with another.

CHECKLIST FOR DISPLAY DESIGN PRINCIPLES

1. Are the most important displays in the most prominent area t eye level?

2. Are the display watched continuously in the center of the control panel; those watched only during certain operations grouped together farther from the center?

3. Are the display indicators (pointer, marker) designed to foster eye scan that goes horizontally left to right, or vertically bottom to top?

4. Is the display interpretable under various lighting conditions, e.g., strong day light or night conditions?

5. Is the display presenting indications which are easily verbalized or visualized?

6. Is the display informing the operator as accurately as necessary, but no more accurately than required?

7. Are displays changing or with changed indication easy to detect?

8. Is the display providing information in an immediately useable form without requiring calculation or translation into other units?

9. Is the displays free from error-producing features such as cause orientation-reversal on the artificial horizon and misreading of multi-revolution or multi-pointer

dials?

10. Is the displays fostering the recognition of errors, so that they do not persist?

11. Is the display informing the operator in which direction to operate the control?

12. Is the display informing the operator in which direction to operate the control?

13. Is the display informing the operator when, how much, and for how long to move the control?

14. Are the warning and emergency displays as near as possible to the central line of sight?

15. Are the warning and emergency displays providing unambiguous consistent information with immediate obvious meaning?

TEST PROCEDURES FOR CONTROL EVALUATION

The control devices to be evaluated include:

a. Toggle switches,

b. Pushbutton switches,

c. Rotary switches,

d. Continuously variable controls,

e. Circuit breakers.

GENERAL PROCEDURES

Controls should be evaluated for adequacy of coding (is it possible to discriminate quickly among adjacent or similar switches, knobs, pushbuttons, etc?); arrangement in relationships to associated displays; consistency of control-display movements; location and design with respect to possible accidental activation; location with respect to aviator's optimum position, (does he have to reach too far, or move his head beyond safe limits to activate the control?), the effects of g (and unusual attitudes) on control movement, consistency of effects throughout flight envelope, adequacy of labelling for multi-mode controls.

In general, the operator does the evaluation to see if the controls in any way will

cause him to make an incorrect response. To aid in this evaluation a listing of common control errors is presented.

CONTROL ERRORS MOST OFTEN ENCOUNTERED BY OPERATORS

a. Confusion of Controls

This most often results from improper control-display compatibility and arrangement of controls.

b. Manipulation of a control in the wrong direction.

This most often results from incompatibility in relation to operator's expectations.

c. Forgetting to use a particular control.

This usually results from poor control arrangement.

d. Accidently moving the wrong control.

This usually results from poor control arrangement.

e. Inability to reach a control.

Usually results from improper use of known anthropometric criteria.

TEST PROCEDURES FOR CONTROL-DISPLAY COMPATIBILITY

GENERAL PROCEDURES

Control-display interrelationships are an essential part of crew station evaluation. In effect the operator seeks to determine how well the controls and displays work together. To aid in the evaluation a checklist of control-display design principle is presented.

CONTROL-DISPLAY DESIGN PRINCIPLES CHECKLIST

1. Have the controls and displays with the same function been grouped together on the panel? For example are the engine displays and controls separate from flight instruments?

2. Are the most critical displays and controls placed in the easiest to see and easiest to reach places?

3. From one airplane model to another, are the fundamental display-control arrangements similar? For example, are landing gear and flap controls similarly placed and coded, regardless of airplane?

4. Insure that no one sense or part of the body should be overloaded with sensing or action tasks that can be accomplished by other parts. Their right hand shouldn't do all the work.

5. Do the required displays and controls have an optimum location? For example, for maximum arm pull strength, you need arm and shoulder involvement at a point straight out from the shoulder. Displays are easiest to see at eye height directly in front of the operator. Controls to be used "blind" should be right in front and quite high on the panel.

6. Are frequently used elements in preferred locations? As an illustration, during a straight climbout it was found that pilots spend nearly three-fourths of their time on looking at three instruments: air speed, directional gyro, and gyro horizon.

7. Have the sequence of actions been adequately layed out in the system? For example, if control Y is always to be activated right after control X, put Y right next to X, etc.

TEST PROCEDURES FOR BIOENVIRONMENTAL EVALUATION

GENERAL PROCEDURES

The Bioenvironmental evaluation seeks to determine the effects of illumination, atmospheric conditions and noise on operator performance.

Atmospheric and acoustic evaluations generally require extensive equipment installation in order to obtain the necessary air and acoustic samples for laboratory evaluation. However, the operator can make a qualitative evaluation of both air and noise. In the case of air purity he should be on the alert for fumes under start, run up, downwind taxi, gun or rocket firing and refueling operations.

As for noise, he can subjectively determine if the noise seems excessive under cruise, climb or maneuvering conditions. With illumination a more detailed crew station evaluation can be accomplished.

ILLUMINATION

Generally the operator should evaluate the lighting system for instrument and panel visibility. He should determine if the lighting system is useful throughout the flight envelope and during all missions? He should evaluate the entire crew station for glare spots, obscured or hidden sections, standby provisions and reliability.

To aid in your illumination evaluation a list of common lighting errors are presented. In addition, a sequential procedure for conducting the lighting evaluation is given.

COMMON ILLUMINATION ERRORS

1. Too much, as well as too little, light for the task.

2. Poorly distributed light that causes bright spots within various displays and panels.

3. Exposing the eye to the light source.

4. Lack of flexibility for operator control of workplace lighting; or too much individual control.

5. Lack of consideration for the total functional lighting requirement e.g., maintenance, as well as operational tasks.

6. Light directed "at people" rather than on the task they perform.

7. Illumination system design which cannot be maintained.

8. Lack of color and quality compatibility between illumination and workplace surface and materials.

LIGHTING EVALUATION PROCEDURE

1. Position yourself in the crew station attired in complete flight clothing and equipment. It is advisable to take a recording device with you (tape recorder is preferred).

2. Cover the canopy with an opaque cover preventing any ambient light from entering. This allows you to conduct the evaluation in day or night conditions.

3. Supply electrical power to the aircraft for interior light actuation.

4. Adjust the seat to place your eyes in the design eye position (or where you normally fly).

5. Allow your eyes to become dark adapted.

6. Check the auxiliary light first. It should be suitable for minimum illumination even if all other lights would be out.

7. After the auxiliary light evaluation, systematically activate all light controls in the cockpit. As you vary the intensity look for instrument lights which extinguish before others as you adjust from bright to OFF. Look for brightness in balance such that with a given light adjustment, some instruments may be too bright or too dim when most other instruments on that lighting control are at an average intensity. Identify any glare or reflection which might require shielding.

8. Adjust your seat to various positions to determine if lighting is sufficient at different eye levels.

9. Record any deficiencies noted.

SUMMARY CHECKLIST OF GOOD CREW STATION LIGHTING DESIGN

1. Is there suitable brightness for the task?

2. Is there uniform lighting on the task?

3. Is there suitable brightness contrast between task and background?

4. Is there a lack of glare from either the light source or the work surface?

5. Is there suitable quality and color of illuminates and surfaces?

TEST PROCEDURES FOR CREWSTATION VISIBILITY, STANDARDIZATION, AND PROCEDURES

To aid you in your evaluation general guidelines are presented below on visibility, standardization, and procedures.

CREW STATION VISIBILITY

You should examine the crew station to determine if there are any visual angles

subtended by wind screen and canopy, specific blind spots, relation of visibility limitations to specific phases of mission (e.g., taxiing, take-off, landing). In other words you are concerned with any visual problem that may restrict performances.

INTER-AIRCRAFT STANDARDIZATION

The crew station should be given a general evaluation to determine if inter-aircraft standardization has been maintained. Note specific points of similarity and difference among all different types or models of aircraft in current use. (especially, note control or display reversals of function, reference, or location). The lack of crew station standardization can only lead to increased training requirements, transition times and poor performance.

PROCEDURAL SEQUENCE

The crew station should be evaluated to determine if start, take-off, landing and emergency procedures have been assembled as effectively as possible. Examine relationships between operating sequences and display-control locations; number, frequency, and timing of discrete responses in required sequences (can check-off and other procedures be improved by reorganizing the sequence?).

CHECKLIST FOR AUTOMATED ESCAPE SYSTEMS

REF: MIL-S-18471

ESCAPE SYSTEM CAPABILITY

1. Will the system provide safe escape for all crewmembers throughout the entire flight envelope including adverse attitudes and high sink rate conditions?

2. Will the system function under water?

3. Are the ground and water ditching provision satisfactory?

CREW STATION NORMAL INGRESS/EGRESS PROCEDURES:

1. Is the escape system compatible with each aircrew station in which it is installed?

2. Can each crewmember readily ingress to and egress from their respective cockpit/crew stations?

3. Are ground safety devices adequate and readily visible?

4. Are the personnel services connections readily accessible?

5. Are personnel restraint straps routing procedures "Murphy" proof?

CREW STATION ACCOMMODATIONS:

1. Does the ejection seat accommodate the 3rd and 98th percentile crewmen, wearing applicable flight clothing?

2. Is crew comfort optimized? Is their adequate clearance?

3. Is their adequate clearance between the canopy/radiation shield and helmet of 98th percentile seated head height aircrewmen, positioned at the design eye position, to permit unobstructed pulling of the face curtains?

4. Are the emergency controls accessible to 3rd and 98th percentile aircrewmen, throughout the range of seat adjustment and while restrained in a full back position?

SEAT ADJUSTMENT

1. Is their sufficient vertical seat adjustment to permit the 3rd and 98th percentile sitting eye height crewman to adjust their eyes to the design eye position?

2. Does the adjustment afford the 3rd through 98th percentile seated head height crewmember adequate vision during landing/takeoff, etc?

3. Does maximum vertical travel expose the 3rd through 98th percentile seated head height crewman to potential canopy collisions/face curtain interference problems?

4. Is their adequate clearance between the seat and 3rd and 98th percentile crewman and aircraft controls functional throw envelope, throughout the entire seat adjustment range?

RECURRING DESIGN PROBLEMS

Finally, it is worth noting that studies have found that certain design deficiencies crop up again and again, even though they are considered to be major problem areas that affect the safety of flight. These include:

a. Nonstandardization of instrument grouping exclusive of the basic flight

instrument and engine instrument group.

b. Instruments which are too small and with markings which are not legible for fast and easy reading.

c. Nonstandard grouping and/or placement of warning lights which tend to confuse or distract the pilot. In some instances the lights are located out of the pilot's line of vision.

d. False fire warnings, caused by internal shorts, malfunction of sensing elements, etc.

The above listed problems continue to plague modern day weapons systems. It is only by adherence to human engineering design principles will we be able to eliminate them.

APPENDIX B

ADDITIONAL REFERENCES

AND

GUIDANCE DOCUMENTS

REFERENCED DOCUMENTS

Issues of Documents - The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this standard to the extent specified herein.

SPECIFICATIONS

MILITARY

MIL-W-5044	Walkway Coating and Matting, Nonslip, Aircraft
MIL-W-5050	Walkway Coating and Matting, Nonslip, Aircraft Application of
MIL-L-5667	Lighting Equipment, Aircraft Instrument Panel, General Specification for Installation of
MIL-P-7788	Panels, Information, Integrally Illuminated
MIL-S-9479	Seat, Upward Ejection, Aircraft
MIL-A-8806	Acoustical Noise Level in Aircraft, General Specification for
MIL-S-008806	Sound Pressure Levels in Aircraft, General Specification for
MIL-M-18012	Markings for Aircrew Station Displays, Design and Configuration
MIL-S-18471	Seat System, Ejectable, Aircraft, General Specification for
MIL-A-23121	Aircraft Environmental, Escape and Survival Cock-pit Capsule Systems, General Specification for
MIL-L-25467	Lighting, Integral, Aircraft Instrument, General Specification for
MIL-C-25050	Colors, Aeronautical Lights and Lighting Equipment, General Specification for

MIL-C-25969	Capsule, Emergency Escape System, General Specification for
MIL-T-23991	Training Devices, Military, General Specification for

STANDARDS

FEDERAL

FED-STD-515/17	Outside Rearview Mirror(s) for Automotive Vehicles
FED-STD-595	Colors

MILITARY

MIL-STD-12	Abbreviation for Use on Drawings, Specifications, Standards, and in Technical Documents
MIL-STD-129	Marking for Shipment and Storage
MIL-STD-130	Identification Markings of U.S. Military Property
MIL-STD-195	Marking of Connections for Electric Assemblies
MIL-STD-203	Aircrew Station Controls and Displays for Fixed Wing Aircraft
MIL-STD-250	Aircrew Station Controls and Displays for Rotary Wing Aircraft
MIL-STD-280	Definition of Item Levels, Item Interchangeability, Models and other Terms
MIL-STD-411	Aircrew Station Signals
MIL-STD-415	Test Points and Test Facilities for Electronic Systems and Associated Equipment, Design Standard for
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-681	Identification Coding and Application of Hookup and Lead Wire

MIL-STD-740	Airborne and Structureborne Noise Measurements and Acceptance Criteria of Shipboard Equipment
MIL-STD-783	Legends for Use in Aircrew Stations and on Airborne Equipment
MIL-STD-1179	Lamp, Reflectors and Associated Signalling Equipment for Military Vehicles
MIL-STD-1180	Safety Standards for Military Ground Vehicles
MIL-STD-1247	Identification of Pipe, Hose and Tube Lines for Aircraft, Missile and Space Systems
MIL-STD-1280	Keyboard Arrangements
MIL-STD-1333	Aircrew Station Geometry for Military Aircraft
MIL-STD-1348	Knobs, Control, Selection of
MIL-STD-1473	Standard General Requirements for Color and Marking of Army Materiel
MIL-STD-1474	Noise Limits for Army Materiel
MIL-STD-1472C	Human Engineering Design Criteria for Military Systems, Equipment, and Facilities

HANDBOOKS

MILITARY

DOD-HDBK-743	Anthropometry of US Military Personnel
MIL-HDBK-759	Human Factors Engineering Design for Army Materiel

PUBLICATIONS

NAVY

BUMEDINST 6260.6	Hearing Conservation Program

AIR FORCE

AFR 161-35	Hazardous Noise Exposure (Regulation)

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

Other Publications - The following documents form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

Human Engineering Guide to Equipment Design, 1972 Edition

(Application for copies of the above publication should be addressed to the Superintendent of Documents, US Government Printing Office, Washington, DC 20402)

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

ANSI S1.1 1960	Acoustical Terminology
ANSI S1.4	Sound Level Meters
ANSI S1.6 1967	Preferred Frequencies and Band Numbers for Acoustical Measurements
ANSI S3.2 1960	Monosyllabic Word Intelligibility, Method for Measurement of
ANSI S3.5 1969	Articulation Index, Methods for the Calculation of

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM E 380-76	Standard for Metric Practice

INTERNATIONAL STANDARDIZATION ORGANIZATION (ISO)

ISO DIS 2631	Guide to the Evaluation of Human Exposure to Whole Body Vibration

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)

SAE J925	Minimum Access Dimensions for Construction and Industrial Machinery

a. Copies of ASTM E 380-76 should be obtained from the procuring activity or as directed by the contracting officer, from the DoD Single Stock Point, Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

b. Application for copies of ANSI S1.1, 1.4, 1.6 and 3.2, and ISO DIS 2631 should be addressed to American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.

c. Application for copies of SAE J925 should be addressed to Society of Automotive Engineers, 2 Pennsylvania Plaza, New York, NY 10001.

Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal Agencies.

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GUIDANCE DOCUMENTS

SCOPE

The documents listed in this appendix provide supplementary information, criteria, and guidance that may be used, as applicable, to assist the designer in complying with the requirements of this standard. Their application is not to be regarded as mandatory, unless so specified by the procuring activity.

TRI-SERVICE PUBLICATIONS

MIL-H-46855	Human Engineering Requirements for Military Systems, Equipment and Facilities
MIL-HDBK-141	Optical Design
DOD-HDBK-743	Anthropometry of US Military Personnel

ARMY PUBLICATIONS

<u>Regulations</u>

AR 40-14	Control and Recording Procedures, Occupational Exposure to Ionizing Radiation
AR 385-16	Safety for Systems, Associated Subsystems and Equipment
AR 700-52	Licensing and Control of Sources of Ionizing Radiation

<u>Pamphlets & Bulletins</u>

AMCP 706-134	Maintainability Guide for Design (AD 823 539)
TB MED 62	Diagnostic X-Ray, Therapeutic X-Ray, and Gamma Bean Protection for Energies up to 10 Million Electron Volts
TB MED 501	Hearing Conservation
TB MED 270	Control of Hazards to Health from Microwave Radiation

TB MED 279	Control of Hazards to Health from Laser Radiation

Design Criteria Handbook

MIL-HDBK-759	Human Factors Engineering Design for Army Materiel

Reports

Aviation Sys Cmd AVSCOM Rept 75-47	Study to Determine the Impact of Aircrew Anthropometry on Airframe Configuration
Natick Laboratories TR EPT-2	Reference Anthropometry of the Artic Equipped Soldier (AD 449 4831)
Natic Laboratories TR 73-51-CE	The Carrying of Loads within an Infantry Company (AD 762 559)
USAAMRDL	Crash Survival Design Guide (Revised 1971)
USAHEL TM 4-77	A Human Factors Evaluation of a Vertical Scale Instrument Display System for the OV-1D Aircraft (AD A03 6050)

NAVY PUBLICATIONS

Reports

NATC Report TM 77-1 SY	Analysis of Flight Clothing Effects on Aircrew Station Geometry (AD A046260)
NAMRL Report 1164	Empirical Reduction in Potential User Population as the Result of Imposed Multivariate Anthropometric Limits (AD 752 032)
NAVMISCEN Report TP-74-6	Reduction in Potential User Population as the Result of Imposed Anthropometric Limits: Monte Carlo Estimation (AD 919 319L)
NAVSHIPS 94323	Human Engineering Guidelines for Maintainability

NEL Report 688	Listening to Differentially Filtered Competing Voice Messages
NRL Report 155	Premodulation Speech Clipping and Filtering: Their Effects on the Intelligibility of Speech
PACMISTESTCEN Report TM-75-46	The Accommodated Proportion of a Potential User Population: Compilation and Comparisons of Methods for Estimation
PACMISTESTCEN Report TP-75-49	Computerized Accommodated Percentage (CAPE) Model for Cockpit Analysis and other Exclusion Studies (AD B008 948L)
PACMISTESTCEN Report TP-76-1	Improved Seat, Console and Workplace Design (AD A040 479)
PACMISTESTCEN Report TP-76-36	Recommended Human Exposure Limits for Very-Low-Frequency Vibration
PACMISTESTCEN Report TP-76-46	Computerized Accommodated Percentage Evaluation: Review and Prospectus (AD A035 205)

Notes

NAVMEDNOTE 6260	Hazardous Noise Areas, Equipment, Machine and Tools; Identification of

AIR FORCE PUBLICATIONS

Manuals

AFM 127-201	Missile Safety Handbook
AFP 160-6-7	Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radio-Nuclides in Air and Water for Occupational Exposure

Reports

AFSWC TR 59-11	Human Factors Handbook for Design of Transporting, Positioning, and Lifting Ground Support Equipment (AD 227 311)
AFSWC TR 59-12	Human Factors Handbook for Design of Testing and Monitoring Ground Support Equipment (AD 227 312)
AFSWC TR 59-13	Human Factors Handbook for Design of Protective and Storage Ground Support Equipment (AD 227 313)
AMRL TDR 64-59	Reach Capability of the USAF Population (AD 608 269)
AMRL TR 65-73	Anthropometry of Common Working Positions (AD 632 241)
AMRL TR 66-27	Aperture Sizes and Depths of Reach for One and Two-Handed Tasks (AD 646 716)
AMRL TR 68-24	Clearance and Performance Values for the Bare-Handed and the Pressure-Gloved (AD 681 457)
AMRL TR 69-6	Anthropometric Dimensions of Air Force Pressure-Suited Personnel for Workspace and Design Criteria (AD 697 022)
AMRL TR 70-114	Horizontal Static Forces Exerted by Men Standing in Common Working Positions on Surfaces of Various Tractions (AD 720 252)
ASD TR 61-381	Guide to the Design of Mechanical Equipment for Maintainability (AD 271 477)
ASD TR 61-424	Guide to Integrated System Design for Maintainability (AD 271 477)

ESD TR 62-4	A Test of the 20 Band and Octave Band Methods of Computing the Articulation Index (AD 271 606)
ESD TR 63-403	Psychoacoustic Speech Test: A Modified Rhyme Test
FDL TDR 64-86	Investigation of Aerospace Vehicle Crew Station Criteria (AD 452 187)
RADC TDR-63-315	Criteria for Group Display Chains for the 1962-1965 Time Period (AD 283 390)
WADC TR 52-204	Handbook of Acoustic Noise Control (AD 18 260)
WADC TR 54-520	The Anthropometry of Work Positions (AD 110 573)
WADC TR 55-159	Space Requirements of the Seated Operator (AD 87 892)
WADC TR 56-218	Guide to the Design of Electronic Equipment for Maintainability (AD 101 729)
WADC TN 57-248	Acoustical Criteria for Work Spaces, Living Quarters, and Other Areas on Air Bases (AD 130 839)
WADD TR 58-474	The Effect of Team Size and Intermember Communication on Decision-Making Performance (AD 215 621)
WADD TR 60-814	Audio Warning Signals for Air Force Weapon Systems (AD 258 477)

Air Force Systems Command Design Handbooks

Copies of Air Force Systems Command design criteria handbooks may be obtained by nongovernmental organizations when compliance therewith is required by a Government contract, or when possession of the handbook will otherwise benefit the Government. Requests for the following handbooks should be directed to 4950/TZHM, Wright-Patterson AFB, OH 45433:

AFSC DH 1-1	General Index and Reference

AFSC DH 1-3	Human Factors Engineering
AFSC DH 1-6	System Safety
AFSC DH 2-1	Airframe
AFSC DH 2-2	Crew Stations and Passenger Accommodations
AFSC DH 2-3	Propulsion and Power
AFSC DH 2-6	Ground Equipment and Facilities

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

Copies of the following standards can be obtained at a nominal cost from the ANSI, 1440 Broadway, New York, NY 10018.

A9.1	Building Exists Code (NFPA 101)
A11.1	Practice for Industrial Lighting
A12	Safety Code for Floor and Wall Openings, Railings and Toe Boards
A14.3	Safety Code for Fixed Ladders
C1	National Electrical Code (NFPA 70)
C2	National Electrical Safety Code (NBS H30)
S1.11-1966	Octave, Half-Octave and Third-Octave Band Filter Sets
Z35.1	Specifications for Industrial Accident Prevention Signs
Z136.1	The Safe Use of Lasers

BOOKS

The documents listed below are normally available in general and technical libraries:

a. A Collation of Anthropometry, J. W. Garett and K. W. Kennedy. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. 1971. (2 Volumes) (AD 723 629; Library of Congress Catalog Car No. 74-607818).

b. ASHRAE Guide and Data Book, latest edition - American Society of Heating, Refrigerating, and Air Conditioning Engineers, New York, N.Y.

c. Bioastronautics Data Book, Second Edition, J. F. Parker and V. R. West, Eds., NASA Sp-3006, Supt of Documents, U.S. Govt Printing Office, Washington, D.C. 20402.

d. General Safety Requirements - U.S. Army Engineer Manual 385-1-1.

e. Guide to Human Engineering Design for Visual Displays, D. Meister and D. J. Sullivan, The Bunker-Ramo Corp., Contract No. N00014-68-C-027E, Work Unit No. NR196-080 (AD 693 237), Office of Naval Research, 30 August 1969.

f. Human Engineering Guide to Equipment Design - H. P. Van Cott, and R. G. Kinkade, Eds, Supt of Documents, US Govt Printing Office, Washington, D.C. 20402, 1972 (Library of Congress Catalog Card No. 72-600054).

g. Industrial Ventilation, Manual of Recommended Practice - 12th Edition, 1972, American Conference of Governmental Industrial Hygienists, Committee on Industrial Ventilation, P.O. Box 453, Lansing, Michigan.

h. Lighting Handbook - Illuminating Engineering Society (IES), latest edition.

i. Symbol Source Book, H. Dreyfuss, 1972, McGraw-Hill Book Company, Library of Congress Card No. 71-172261.

j. The Human Body in Equipment Design, A. Damon, H. W. Stoudt, and R. A. McFarland, Harvard University Press, Cambridge, Mass, 1966. (Library of Congress Catalog Card No. 65-22067).

k. U.S. Naval Aerospace Physiologists Manual, NAVAIROO-807-99, 1972.

l. Engineering Anthropometry Methods. J. A. Roebuck, K. H. E. Kroemer and W. G. Thompson, John Wiley and Sons, New York, N.Y. 1975 (Library of Congress Catalog No. 74-34272).

APPENDIX C

LIST OF REFERENCES

LIST OF REFERENCES

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2. Bailey, R. W. Human Performance Engineering: A Guide for System Designers. Prentice-Hall, Inc., Englewood, N.J., 1982.

3. Boehm-David, R., R. E. Curry, E. L. Wiener, and R. L. Harrison. 1981. Human Factors of Flight-Deck Automation--NASA/Industry Workshop. Moffett Field, California: National Aeronautics and Space Administration Ames Research Center. (NASA Technical Memorandum 81260).

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10. Environmental Engineering, USAF Design Handbook, serial 1-0, General AFSC DH 1-5, 3rd Edition, Headquarters AFSC, 10 Mar 74.

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23. Human Engineering Requirements for Military Systems, Equipment, and Facilities. MIL-H-46855B, Department of Defense, 31 Jan 79.

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29. Life Support, USAF Design Handbook, serial 2-0, General AFSC DH 2-8, 1st Edition, Headquarters AFSC, 115 Dec 71.

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